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General Performance Analysis of Binary Fading Channels with Measurement Based Feedback Channel Equalization

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***Abstract*—This paper presents a new general analytical technique for exact error rate analysis of coherent and noncoherent binary wireless communication systems in the presence of nonselective slow fading, additive white Gaussian noise (AWGN) and using measurement based feedback channel equalization technique by estimating the fading channel gain in an independent noisy pilot (measuring) channel. New exact bit error rate expressions are derived for coherent and orthogonal noncoherent binary system and the presence of different fading statistics. These results are derived in the case of signals experiencing Rayleigh, Rician or Nakagami-m fading. The results can be extended to arbitrary M-ary modulation.**

***Index Terms*—Error analysis, binary wireless communication, fading mitigation with feedback, fading channel gain estimation, radio communication, closed loop power control.**

I. INTRODUCTION

The wireless and mobile technologies have improved significantly in the last two decades. In those years intensive investigations of wireless systems with closed-loop power control and channel equalization have carried out. This area in different contexts but always raised in every generation of mobile communication systems. The closed-loop power control solves the so-called near-far problem primarily, however the channel equalization compensates the effect of random fluctuation (fading) appearing in the radio channel. Traditionally, the prior problem is used to be solved with a high delay closed-loop power control system, while solution of the latter one requires diversity techniques ([5]). The closed-loop power control had an important role in the early mobile technologies (i.e. NMT and GSM), however its significance increased when the third generation CDMA systems were introduced. These systems require power control for the in-system interference coordination to provide reliable and fair communication. This topic is in focus since then, numerous papers were published ([6]-[20]) in the recent years. The closed-loop power control is also important in fourth generation systems (like LTE and its advanced versions) in connection with MIMO technologies ([21]-[29]). It has central role in the new direction of mobile communication systems, namely in the cognitive radio systems ([30]-[35]). This is motivated by the recent standardization trends towards permitting different heterogeneous communication systems to coexist and share a common wireless channel (e.g., unlicensed spectrum, opportunistic and dynamic spectrum access, spectrum underlay or overlay, ...).

To date, most research have focused on the performance of separated closed- loop power control system and diversity techniques to solve the near-far problem and the channel equalization in presence of white Gaussian noise and some special types of intentional interference. The most relevant to the present paper are those that analyses the error rate of the closed-loop power control scheme for the multi-rate services in the third and forth generation wideband systems. In [36] the authors demonstrate that the long scrambling pseudo-noise code, besides its well known feature in differentiating users and base stations, can improve power control false command over a frequency-selective fading channel as well. It is shown that the closed-loop power control error is a composite function of the spreading factor, target E_b/N_0 and Doppler frequency. In [37] the authors proposed an algorithm that computes the solution to the power control problem with closed-loop effects, and analytical and simulation results show that the algorithm converges under the same conditions as that given in the earlier results. In [38] the authors analyze the system performance of a truncated closed-loop power-control (TCPC) scheme for uplink in direct-sequence/code-division multiple-access cellular systems over frequency-selective fading channels. Closed-form formulas are successfully derived for performance measures, such as system capacity, average system transmission rate, MS average transmission rate, MS power consumption, and MS suspension delay. In [39] the authors propose smart step closed-loop power control (SSPC) algorithm in a DS-CDMA receiver in the presence of frequency-selective Rayleigh fading. This receiver consists of three stages. In the first stage the desired users' signal in an arbitrary path is passed and the inter-path interference (IPI) is reduced. Also in this stage, the multiple access interference (MAI) from other users is reduced. Thus, the matched filter (MF) can be used for the MAI and IPI reduction in the second stage. Also in the third stage, the output signals from the matched filters are combined according to the conventional maximal ratio combining (MRC) principle and then are fed into the decision circuit of the desired user. In [40] the performance of SIR (signal to interference ratio)-based closed loop power control (CLPC) is analytically analyzed. An analytical expression of the CLPC under fast fading is also produced. Finally a quantized-step size power control algorithm, replacing the hard limiter is considered.

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The main aim of this paper is to present a unified analytical method for the accurate error rate analysis of coherent BPSK and orthogonal noncoherent BFSK in wireless communication systems with fast closed-loop power control systems subjected to general fading and using a measuring based channel estimation in a separated noisy channel. The main contributions are new exact expressions for error rates of coherent BPSK and orthogonal noncoherent BFSK in different fading environments (including Rayleigh, Nakagami-*m*, and Rician fading) and subjected to an non-exact channel transmission parameter measured in a noisy pilot channel. The results of this paper can be used to compare the performance of a coherent BPSK and orthogonal noncoherent BFSK wireless network that has a fast closed-loop power control system and uses diversity combining algorithms to parallel solve the near-far problem and channel equalization.

This paper is organized as follows. The basic model is described in Section II. Section III and Section IV present the unified method for the evaluation of the error probabilities in the case of coherent and noncoherent binary transmission. In Section V the average SNR is derived in the case of power limitation in the transmitter and in Section VI application examples are presented in the case of different fading parameters and power limitation factors. Section VII concludes the paper.

II. THE MODEL

The lowpass equivalent complex-valued representation of the binary modulated signal $\mathbf{r}^*$ without channel equalization at the receiver front end during a signalling interval is given by

$$\mathbf{r}^* = \sqrt{E_s}\mathbf{g}^{(b)}z + \mathbf{n}, \quad t \in (0,T], \tag{1}$$

where E_s is the average symbol energy without fading and power control, T is the binary symbol time, $b \in [0,1]$ is the binary symbol and $\left\{\mathbf{g}^{(b)},\ \left\|\mathbf{g}^{(b)}\right\|^2 = 1\right\}$ are the lowpass equivalent complex-valued representation of the elementary signals (in coherent case $\mathbf{g}^{(0)} = -\mathbf{g}^{(1)}$, and in noncoherent case $\left\langle \mathbf{g}^{(0)}, \mathbf{g}^{(1)} \right\rangle = 0$ typically), z is the complex fading channel gain and $\mathbf{n}$ is the lowpass equivalent complex-valued representation of the additive white Gaussian noise (AWGN) with $\mathbb{E}\left[\mathbf{n}\mathbf{n}^*\right] = N_0\mathbf{I}$, and $\mathbf{I}$ is the unity matrix. z is a RV that represents the instantaneous amplitude of the received binary signal ($\mathbb{E}\left[|z|^2\right] = 1$). The distribution of z depends on the fading scenario. In this paper, we consider three different types of nonselective slow fading scenarios, namely: Rayleigh, Rician and Nakagami-*m* fading models, and we suppose that the fading channel gain is estimated in the receiver by measurement in an independent pilot channel and the fading channel gain of the communication and measuring (pilot) channel are equivalent.

In our approach the fading channel gain is estimated at the receiver based on the use of an unmodulated pilot signal in an independent pilot (measuring) channel, therefore the lowpass equivalent complex-valued representation of the measuring signal at the receiver front end during a measuring interval is

$$\overline{\mathbf{r}} = \sqrt{E_0}z + \overline{\mathbf{n}}, \quad t \in \left(0,\overline{T}\right], \tag{2}$$

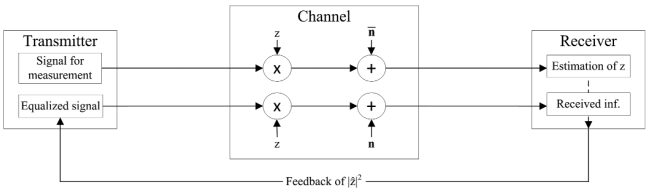

Figure 1. The model of our system. The fading channel gain of the measuring (pilot) and the communication channel are the same (z), but the noises ($\mathbf{n}, \overline{\mathbf{n}}$) are independent. The amplitude of the estimated fading channel gain ($|\widehat{z}|^2$) is fed back to the transmitter via an error-free digital communication channel. The transmitter equalizes the transmitted signal power based on this information.

where E_0 is the mean "symbol" energy of the measuring signal, $\overline{T}$ is the measuring time interval and $\overline{\mathbf{n}}$ is the lowpass equivalent complex-valued representation of the additive white Gaussian noise (AWGN) in the measuring channel with $\mathbb{E}\left[\overline{\mathbf{n}}\overline{\mathbf{n}}^*\right] = N_0\mathbf{I}$. In the paper we assume that the noises of the communication and the measuring (pilot) channel are independent ($\mathbb{E}\left[\mathbf{n}\overline{\mathbf{n}}^*\right] = \mathbf{0}$).

In our approach - for the fading suppression (channel equalization) - the transmitted signal is corrected by the estimated of the fading channel gain, where the best estimation of z is given by

$$\widehat{z} = \frac{\overline{\mathbf{r}}}{\sqrt{E_0}} = z + \frac{\overline{\mathbf{n}}}{\sqrt{E_0}}. \tag{3}$$

It is easy to show, that $\widehat{z}$ is a conditionally complex Gaussian RV if z is given, the mean value of $\widehat{z}$ is $\mathbb{E}\left[\widehat{z}\right] = z$ and the variance of it is given by

$$\mathbb{E}\left[\left(\widehat{z} - \mathbb{E}\left[\widehat{z}\right]\right)^2\right] = \frac{N_0}{E_0} = \frac{1}{\gamma_0}, \tag{4}$$

where γ_0 is the SNR of the measuring channel without fading. Note that we use an unmodulated pilot signal during the measurement process, hence the received energy via the pilot channel and therefore the accuracy of the fading channel gain estimation depends on the $\overline{T}$ too. If the measurement process and feedback delay is less than the fluctuation of the fading (what is assumed), the noise of the pilot channel ($\overline{\mathbf{n}}$) can be neglected.

In this paper we assume that the result of the measurement in the pilot channel ($|\widehat{z}|^2$) is fed back to the transmitter via a digital communication channel without any error and the transmitter uses this information to correct the transmitted signal power, as represented in Figure 1. The lowpass equivalent complex-valued representation of the corrected binary modulated signal at the receiver front end during a signalling interval is given by

$$\mathbf{r} = \sqrt{E_s}\mathbf{g}^{(b)}\frac{z}{\sqrt{h\left(|\widehat{z}|^2\right)}} + \mathbf{n}, \quad t \in (0,T], \tag{5}$$

where $\sqrt{h\left(|\widehat{z}|^2\right)}$ is the correction function at the transmitter, depending only on the cardinality of $\widehat{z}$, and $\mathbf{r}$ is a conditionally Gaussian RV, if z, $\mathbf{g}^{(b)}$ and $\overline{\mathbf{n}}$ are given. Using the elementary description of the communication systems the effective

conditionally SNR of the communication channel is

$$\Gamma\left(\gamma_s|z,\overline{n}\right)=\frac{E_S}{N_0}\frac{|z|^2}{h\left(\left|z+\frac{\overline{\mathbf{n}}}{\sqrt{E_0}}\right|^2\right)}=$$
$$=\gamma_s\frac{|z|^2}{h\left(\left|z+\frac{\overline{\mathbf{n}}}{\sqrt{E_0}}\right|^2\right)}, \tag{6}$$

where γ_s is the SNR of the communication channel without fading, and throughout this paper we suppose that

$$h(x)=\begin{cases} c & \text{if } |x|\le c \\ |x|^2 & \text{if } |x|>c \end{cases} \tag{7}$$

is a simple threshold function considering an upper limit of the power in the transmitter.

Let us introduce the X and Y random variables as

$$X=|z|^2 \text{ and } Y=\left|z+\frac{\overline{\mathbf{n}}}{\sqrt{E_0}}\right|^2, \tag{8}$$

therefore

$$\Gamma\left(\gamma_s|z,\overline{n}\right)=\gamma_s\frac{X}{h\left(Y\right)}=\gamma_s\frac{X}{Y'}, \tag{9}$$

and

$$h\left(y\right)=y'=\begin{cases} c \text{ if } y\le c \\ y \text{ if } y>c \end{cases} \tag{10}$$

and determine the $f_{Y|X}\left(y|x\right)$ conditional probability density function of Y if X is given. After some simple mathematical manipulations one can get the following result:

$$f_{Y|X}\left(y|x\right)=\gamma_0\exp\left(-\gamma_0\left(x+y\right)\right)I_0\left(2\gamma_0\sqrt{xy}\right), \tag{11}$$

and

$$f_{XY}\left(x,y\right)=\gamma_0\exp\left(-\gamma_0\left(x+y\right)\right)I_0\left(2\gamma_0\sqrt{xy}\right)f_X\left(x\right) \tag{12}$$

therefore the pdf of Y is given by

$$f_Y\left(y\right)=\int_0^\infty\gamma_0\exp\left(-\gamma_0\left(x+y\right)\right)I_0\left(2\gamma_0\sqrt{xy}\right)f_X\left(x\right)dx, \tag{13}$$

where $f_X\left(x\right)$ is the pdf of the fading channel gain, and

$$f_X\left(x\right)=\exp\left(-x\right) \text{ in the case of Rayleigh,} \tag{14}$$

$$f_X\left(x\right)=(1+k)\exp\left(-k-(1+k)\,x\right) \tag{15}$$
$$I_0\left(2\sqrt{k\left(1+k\right)x}\right) \text{ in the case of Rician,}$$

$$f_X\left(x\right)=\tfrac{x^{m-1}}{x!}m^m\exp\left(-mx\right) \tag{16}$$
in the case of Nakagami-*m* fading models.

Using the definition of Y' (10) the pdf of Y' is given by

$$f_{XY'}\left(x,y'\right)=\begin{cases} A\left(x\right)\delta(y'-c)f_X\left(x\right) \text{ if } y'=c \\ f_{Y|X}\left(y'|x\right)f_X\left(x\right) \quad \text{if } y'>c \end{cases} \tag{17}$$

where

$$A\left(x\right)=\int_0^c f_{Y|X}\left(y|x\right)dy. \tag{18}$$

III. Derivation of the average error rate in the case of coherent binary transmission in fading channels

In this section, we present a new method for efficient computation of the average error probability of the coherent binary channels with the above mentioned feedback channel equalization by reducing the number of improper integrals. Our method is able to decrease the complexity of the mathematical problem and to increase the accuracy of the calculation. A key to the proposed method is to transform the conditional error probability function of the fading channel into a special form, which lets us use closed integral formulae and simplify the calculation of the average error rate. Therefore in the next subsection, we simplify the description of the proposed transformation technique, and prove its validity for different type of fading.

It is well known from the literature that the bit error rate of a binary coherent communication system is given by ([1])

$$P_b(\gamma_s|z,\overline{n})=\frac{1}{2}\text{ erfc}\left(\sqrt{\text{SNR}}\right), \tag{19}$$

where SNR is given in (9) and based on the well known lemma ([2]):

$$\frac{1}{2}\text{ erfc}\left(\sqrt{\text{SNR}}\right)=\frac{1}{\pi}\int_0^{\frac{\pi}{2}}\exp\left(-\frac{\text{SNR}}{\cos^2\left(\theta\right)}\right)d\theta, \tag{20}$$

one can arrive at the following general expression of the conditional error probability of the coherent binary system:

$$P_b(\gamma_s|z,\overline{n})=\frac{1}{\pi}\int_0^{\frac{\pi}{2}}\exp\left(-\frac{\gamma_s\,x}{h(y)\cos^2\left(\theta\right)}\right)d\theta. \tag{21}$$

In this part of the paper, we present the new method for efficient computation of the average in (21). For that purpose let us use the Y and X RV-s (5), where Y is a conditionally Rician distributed random variable (if z is given) with pdf (11), as $\overline{\mathbf{n}}$ is a complex Gaussian RV with independent uniformly distributed real and imaginary parts.

Using (21) the conditional error probability function of the coherent receiver we can obtain the error function of P_b after calculating the average according to the Y and X random variables as follows:

$$P_b(\gamma_s)=\frac{1}{\pi}\int_0^{\frac{\pi}{2}}\mathbb{E}\left[\exp\left(-\frac{\gamma_s\,x}{h(y)\cos^2\left(\theta\right)}\right)\right]d\theta, \tag{22}$$

where

$$\mathbb{E}\left[\exp\left(-\tfrac{\gamma_s\,x}{h(y)\cos^2(\theta)}\right)\right]=$$
$$=\int_0^\infty\int_0^\infty\exp\left(-\tfrac{\gamma_s\,x}{h(y)\cos^2(\theta)}\right)f_{XY}\left(x,y\right)dxdy, \tag{23}$$

therefore the error probability can be calculated by the following triple integral (17):

$$P_b(\gamma_s)=\frac{1}{\pi}\int_0^\infty\int_0^\infty\int_0^{\frac{\pi}{2}}\exp\left(-\tfrac{\gamma_s\,x}{h(y)\cos^2(\theta)}\right)$$
$$f_{XY}\left(x,y\right)d\theta dxdy. \tag{24}$$

1) Rayleigh fading: In the case of Rayleigh fading model ($f_X(x) = \exp(-x)$) using (23) and (12) for the calculation of the error probability of the coherent system it is necessary to solve the following integral:

$$\int_0^\infty \exp\left(-x\left(1+\gamma_0+\frac{\gamma_s}{h(y)\cos^2(\theta)}\right)\right) I_0\left(2\gamma_0\sqrt{xy}\right) dx, \tag{25}$$

and using the equation of [4, eq. (4.86)] we can get the following result:

$$\int_0^\infty \exp(-at) I_0\left(2\sqrt{bt}\right) dt = \frac{1}{a}\exp\left(\frac{b}{a}\right), \tag{26}$$

where

$$a = 1+\gamma_0+\frac{\gamma_s}{h(y)\cos^2(\theta)} \text{ and } b = \gamma_0^2 y, \tag{27}$$

therefore one can arrive at the following final equation:

$$P_b(\gamma_S) = \frac{\gamma_0}{\pi}\int_0^{\frac{\pi}{2}}\int_0^\infty \frac{1}{1+\gamma_0+\frac{\gamma_s}{h(y)\cos^2(\theta)}} \exp\left(-\gamma_0 y\frac{1+\frac{\gamma_s}{h(y)\cos^2(\theta)}}{1+\gamma_0+\frac{\gamma_s}{h(y)\cos^2(\theta)}}\right) dy d\theta, \tag{28}$$

where the integral by y should be calculated in two intervals: $\{[0,c];\ h(y)=c\}$ and $\{(c,\infty);\ h(y)=y\}$.

2) Rician fading: In the case of Rice fading model using (23) and (12) for the calculation of the error probability of the coherent system it is necessary to solve the following integral ($f_X(x) = (1+k)\exp(-k-(1+k)x) I_0\left(2\sqrt{k(1+k)x}\right)$):

$$\int_0^\infty \exp\left(-x\left((1+k)+\gamma_0+\frac{\gamma_s}{h(y)\cos^2(\theta)}\right)\right) I_0\left(2\sqrt{k(1+k)x}\right) I_0\left(2\gamma_0\sqrt{xy}\right) dx. \tag{29}$$

Using the serial expansion of $I_0(.)$:

$$I_0\left(2\sqrt{k(1+k)x}\right) = \sum_{l=0}^\infty \frac{k^l(1+k)^l}{l!l!}x^l \tag{30}$$

this integral will be modified as follows:

$$\sum_{l=0}^\infty \frac{k^l(1+k)^l}{l!l!}\int_0^\infty x^l I_0\left(2\gamma_0\sqrt{xy}\right) \exp\left(-x\left((1+k)+\gamma_0+\frac{\gamma_s}{h(y)\cos^2(\theta)}\right)\right) dx, \tag{31}$$

and using the 6.643.2 and 9.220.2 equations of [3, eq. (4.86)] we can get the following final result:

$$P_b(\gamma_S) = \frac{\gamma_0}{\pi}\int_0^{\frac{\pi}{2}}\sum_{l=0}^\infty \frac{k^l(1+k)^l}{l!} \int_0^\infty {}_1F_1\left(l+1,1;\frac{\gamma_0^2 y}{(1+k)+\gamma_0+\frac{\gamma_s}{h(y)\cos^2(\theta)}}\right) \frac{\exp(-\gamma_0 y)\exp(-k)}{\left((1+k)+\gamma_0+\frac{\gamma_s}{h(y)\cos^2(\theta)}\right)^{l+1}} dy d\theta, \tag{32}$$

where ${}_1F_1(.,.;.)$ is the confluent hypergeometric function.

3) Nakagami m-fading: In the case of Nakagami m-fading model ($f_X(x) = \frac{x^{m-1}}{\Gamma(m)}m^m\exp(-mx)$) using (23) and (12) for the calculation of the error probability of the coherent system it is necessary to solve the following integral:

$$\int_0^\infty x^{m-1}\exp\left(-x\left(m+\gamma_0+\frac{\gamma_s}{h(y)\cos^2(\theta)}\right)\right) I_0\left(2\gamma_0\sqrt{xy}\right) dx, \tag{33}$$

and using the 6.643.2 and 9.220.2 equations of [3, eq. (4.86)] we can get the following final result:

$$P_b(\gamma_S) = \frac{\gamma_0 m^m}{\pi}\int_0^{\frac{\pi}{2}}\int_0^\infty \frac{\exp(-\gamma_0 y)}{\left(m+\gamma_0+\frac{\gamma_s}{h(y)\cos^2(\theta)}\right)^m} {}_1F_1\left(m,1;\frac{\gamma_0^2 y}{m+\gamma_0+\frac{\gamma_s}{h(y)\cos^2(\theta)}}\right) dy d\theta, \tag{34}$$

where ${}_1F_1(.,.;.)$ is the confluent hypergeometric function.

To summarize, based on (24) the (28), (32) and (34) equations are new exact expressions for the average error probabilities of the coherent binary fading channels with measurement based feedback channel equalization over different fading channels.

IV. Derivation of the average error rate in the case of noncoherent binary transmission in fading channels

It is well known from the literature that the bit error rate of a noncoherent binary communication system with orthogonal elementary signals is given by ([1])

$$P_b(\gamma_s|z,\overline{n}) = \frac{1}{2}\exp\left(-\frac{\text{SNR}}{2}\right), \tag{35}$$

where SNR is given in (9) and one can arrive at the following general expression of the conditional error probability of the coherent binary system:

$$P_b(\gamma_s|z,\overline{n}) = \frac{1}{2}\exp\left(-\frac{\gamma_s x}{2h(y)}\right), \tag{36}$$

In this part of the paper, we present the noncoherent version of our new method for efficient computation of the average in (36). For that purpose let us use the Y and X RV-s (5), where

Y is a conditionally Rician distributed random variable (if z is given) with pdf (11), as $\overline{\mathrm{n}}$ is a complex Gaussian RV with independent uniformly distributed real and imaginary parts.

Using (36) the conditional error probability function of the coherent receiver we can obtain the error function of P_b after calculating the average according to the Y and X random variables, as follows:

$$P_b(\gamma_s) = \frac{1}{2}\mathbb{E}\left[\exp\left(-\frac{\gamma_s\, x}{2h(y)}\right)\right], \tag{37}$$

where

$$\mathbb{E}\left[\exp\left(-\frac{\gamma_s\, x}{2h(y)}\right)\right] = \int_0^\infty\int_0^\infty \exp\left(-\tfrac{\gamma_s\, x}{2h(y)}\right) f_{XY}\,(x,y)\,dxdy, \tag{38}$$

therefore the error probability can be calculated by the following double integral (17):

$$P_b(\gamma_s) = \frac{1}{2}\int_0^\infty\int_0^\infty \exp\left(-\frac{\gamma_s\, x}{2h(y)}\right) f_{XY}\,(x,y)\,dxdy. \tag{39}$$

1) Rayleigh Fading: Here, ξ is exponentially distributed, $f_\xi(x) = \exp(-x)$, and it can be shown using [3, eq. (6.614.1)] that

$$P_b(\gamma_S) = \frac{\gamma_0}{2}\int_0^\infty \frac{1}{1+\gamma_0+\frac{\gamma_s}{2h(y)}} \exp\left(-\gamma_0 y\frac{1+\frac{\gamma_s}{2h(y)}}{1+\gamma_0+\frac{\gamma_s}{2h(y)}}\right) dy. \tag{40}$$

2) Rician Fading: In this case ξ is distributed according to the non-central chi-square distribution, $f_\xi(x) = (1+k)\,e^{-k}\; e^{-(1+k)x} I_0\left(2\sqrt{k\,(1+k)\,x}\right)$ where k is the Rician factor, and $I_0(.)$ is the modified Bessel function of the first kind and zeroth order.

After similar calculations as in the case of coherent system one can get the following final result:

$$P_b(\gamma_S) = \frac{\gamma_0}{2}\sum_{l=0}^{\infty}\frac{k^l\,(1+k)^l}{l!}\int_0^\infty \frac{\exp(-\gamma_0 y)\exp(-k)}{\left((1+k)+\gamma_0+\frac{\gamma_s}{2h(y)}\right)^{l+1}} {}_1F_1\left(l+1,1;\frac{\gamma_0^2\, y}{(1+k)+\gamma_0+\frac{\gamma_s}{2h(y)}}\right) dy. \tag{41}$$

3) Nakagami fading: In this case, ξ is a gamma RV with $f_\xi(x) = \frac{x^{m-1}}{\Gamma(m)} m^m e^{-mx}$, and it can be shown with the help of [3, eq. (6.631.1)] (equation 6.631.1.) that

$$P_b(\gamma_S) = \frac{\gamma_0 m^m}{2}\int_0^\infty \frac{\exp(-\gamma_0 y)}{\left(m+\gamma_0+\frac{\gamma_s}{2h(y)}\right)^m} {}_1F_1\left(m,1;\frac{\gamma_0^2\, y}{m+\gamma_0+\frac{\gamma_s}{2h(y)}}\right) dy, \tag{42}$$

where ${}_1F_1(.,.;.)$ is the confluent hypergeometric function, defined in [3, eq. (9.210)].

To summarize, based on (39) the (40), (41) and (42) equations are new exact expressions for the average error probabilities of the noncoherent binary fading channels with measurement based feedback channel equalization over different fading channels.

V. Derivation of the average SNR in the case power limitation

The closed-loop power control has an effect on the average transmission power. Namely, the average SNR decreases depending on the actual statistic of the fading channel gain, the estimation error of the channel parameter and the upper limit of the transmission power c. This subsection describes this effect in case of different fading types.

In the proposed system the instantaneous transmission power is calculated as follows:

$$E_t = \frac{E_s}{h(y)} = \frac{E_s}{h\left(\left|z+\frac{\overline{\mathrm{n}}}{\sqrt{E_0}}\right|^2\right)} = \frac{E_s}{y'}, \tag{43}$$

where E_s is the average symbol energy without fading and power control, y' is a realization of the Y' RV defined in (10). In this case the average SNR is given by the following expected value:

$$\mathbb{E}[\mathrm{SNR}] = \mathbb{E}\left[\frac{E_t}{N_0}\right] = \mathbb{E}\left[\frac{E_s}{N_0}\frac{1}{h(Y)}\right] = \gamma_s\mathbb{E}\left[\frac{1}{Y'}\right], \tag{44}$$

from which the average rise of the SNR can be calculated with the following expression:

$$\mathbb{E}\left[\frac{\mathrm{SNR}}{\gamma_s}\right] = \mathbb{E}\left[\frac{1}{Y'}\right] = \int_0^\infty \frac{1}{y'} f_{Y'}\,(y')\,dy' = \int_0^c \frac{1}{c} f_Y\,(y)\,dy + \int_c^\infty \frac{1}{y} f_Y\,(y)\,dy = \int_0^\infty\int_0^c \frac{1}{c} f_{XY}\,(x,y)\,dydx + \int_0^\infty\int_c^\infty \frac{1}{y} f_{XY}\,(x,y)\,dydx. \tag{45}$$

1) Rayleigh fading: Here, ξ is exponentially distributed, $f_\xi(x) = \exp(-x)$, and it can be shown using [3, eq. (6.614.1)] that the average SNR is given by

$$\mathbb{E}\left[\frac{\mathrm{SNR}}{\gamma_s}\right] = \int_0^\infty \frac{1}{h\,(y)}\frac{\gamma_0}{1+\gamma_0}\exp\left(-\frac{\gamma_0}{1+\gamma_0}y\right) dy. \tag{46}$$

2) Rician Fading: In this case ξ is distributed according to the non-central chi-square distribution, $f_\xi(x) = (1+k)\,e^{-k}\; e^{-(1+k)x} I_0\left(2\sqrt{k\,(1+k)\,x}\right)$ where k is the Rician factor, and $I_0(.)$ is the modified Bessel function of the first kind and zeroth order, and after some mathematical manipulations ([3, eq. (6.631.1)], equation 6.631.1.) the average SNR can be calculated as

$$\mathbb{E}\left[\frac{\mathrm{SNR}}{\gamma_s}\right] = \int_0^\infty\sum_{l=0}^{\infty}\frac{k^l\,(1+k)^l}{l!}\frac{\gamma_0\exp(-\gamma_0 y)\exp(-k)}{h\,(y)} \frac{1}{((1+k)+\gamma_0)^{l+1}} {}_1F_1\left(l+1,1;\frac{\gamma_0^2\, y}{(1+k)+\gamma_0}\right) dy, \tag{47}$$

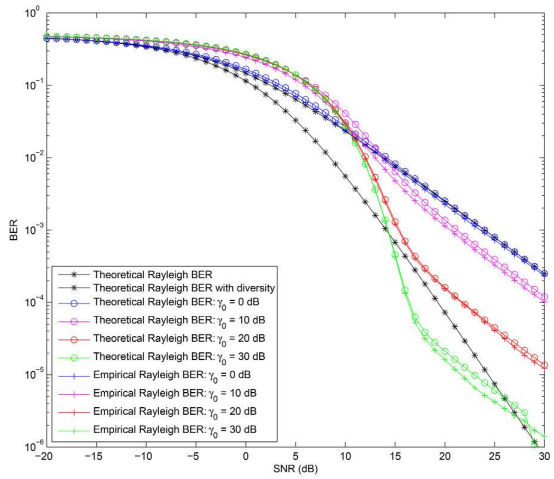

Figure 2. Validation of the theoretical results in the case of coherent binary transmission. Average BER of Rayleigh fading channel against the average SNR, when the SNR of the measuring channel is $\gamma_0 = 0 - 30$ dB and the power limiting factor $c = 0.001$.

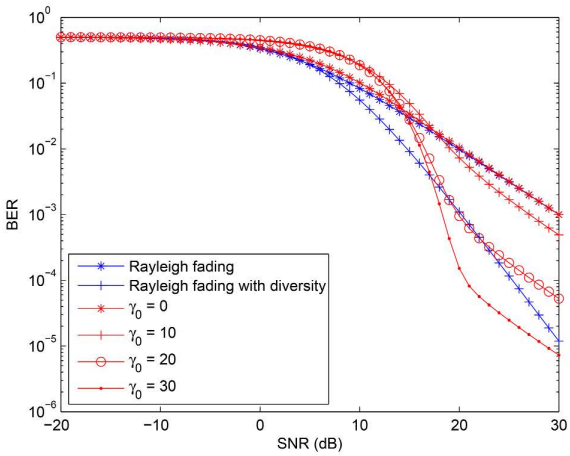

Figure 3. Theoretical results in the case of noncoherent binary transmission. Average BER of Rayleigh fading channel against the average SNR, when the SNR of the measuring channel are $\gamma_0 = 0 - 30$ dB and the power limiting factor is $c = 0.001$.

where ${}_1F_1(.,.;.)$ is the confluent hypergeometric function.

3) Nakagami Fading: In this case, ξ is a gamma RV with $f_\xi(x) = \frac{x^{m-1}}{\Gamma(m)} m^m e^{-mx}$, and it can be shown with the help of [3, eq. (6.631.1)] (equation 6.631.1.) that average SNR can be given by

$$\mathbb{E}\left[\frac{\text{SNR}}{\gamma_s}\right] = \int_0^\infty \frac{1}{h(y)} \gamma_0 \frac{m^m}{(m+\gamma_0)^m} \exp(-\gamma_0 y) \, {}_1F_1\left(m, 1; \frac{\gamma_0^2 y}{m+\gamma_0}\right) dy, \quad (48)$$

where ${}_1F_1(.,.;.)$ is the confluent hypergeometric function.

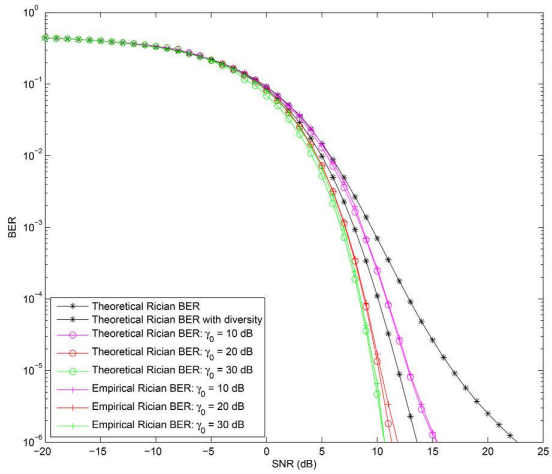

Figure 4. Validation of the theoretical results in the case of coherent binary transmission. Average BER of Rician fading channel against the average SNR, when the SNR of the measuring channel are $\gamma_0 = 0 - 30$ dB, $k = 10$ and the power limiting factor is $c = 0.001$.

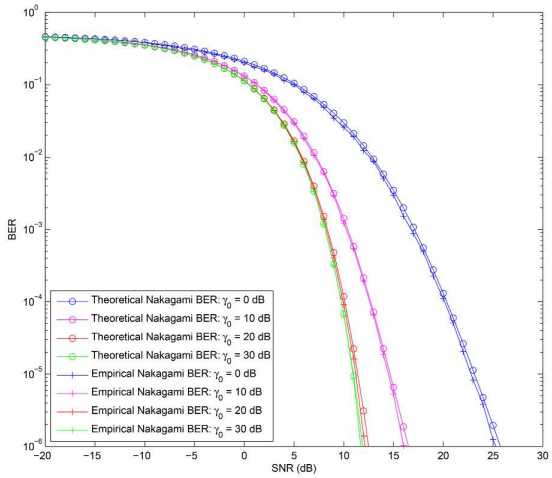

Figure 5. Validation of the theoretical results in the case of coherent binary transmission. Average BER of Nakagami fading channel against the average SNR, when the SNR of the measuring channel are $\gamma_0 = 0 - 30$ dB, $m = 4$ and the power limiting factor is $c = 0.001$.

VI. Numerical results and conclusions

This section of the paper introduces some numerical and simulation results and draws the most important conclusions. Fig. 2–Fig. 9 shows average Bit-Error-Rate probabilities against the average SNR of the communication channel in the interval of $-20 - 30$ dB. It is known from Section II, that the average BER depends on the fading channel gain z, the SNR of the measurement (pilot) channel γ_0 and the parameter of the transmission power limiting factor c. Therefore the results focus on the effect of these dependencies.

Fig. 2 and Fig. 3 show the average BER curves of Rayleigh fading channel against the average SNR in coherent and

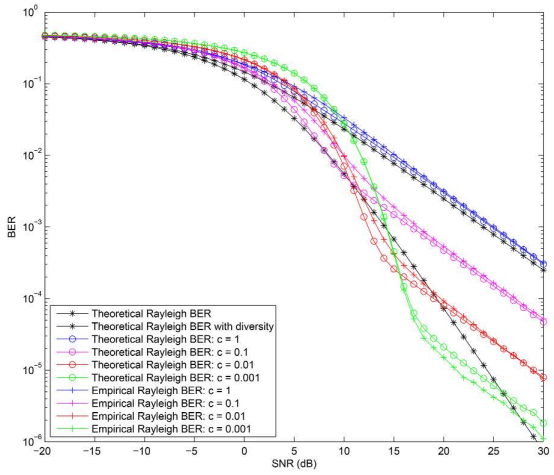

Figure 6. Validation of the theoretical results in the case of coherent binary transmission. Average BER of Rayleigh fading channel against the average SNR, when the SNR of the measuring channel is $\gamma_0 = 30$ dB and the power limiting factors are $c = 1 - 0.001$.

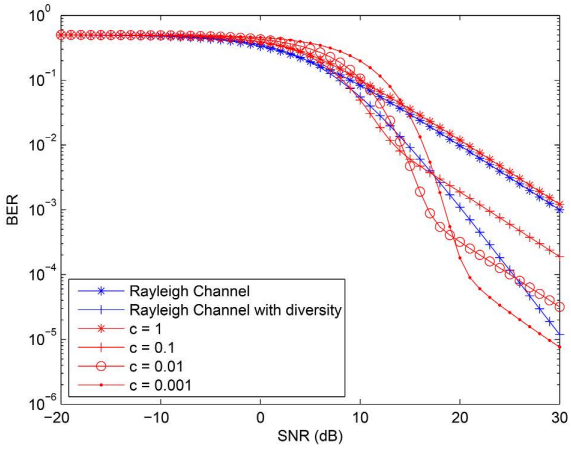

Figure 7. Theoretical results in the case of noncoherent binary transmission. Average BER of Rayleigh fading channel against the average SNR, when the SNR of the measuring channel is $\gamma_0 = 30$ dB and the power limiting factors are $c = 1 - 0.001$.

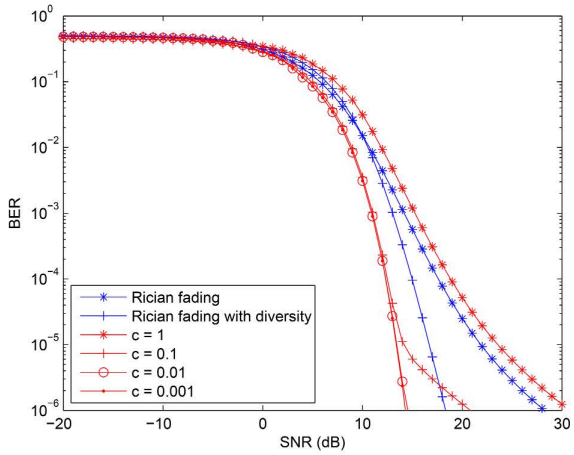

Figure 8. Theoretical results in the case of coherent binary transmission. Average BER of Rician fading channel against the average SNR, when the SNR of the measuring channel is $\gamma_0 = 30$ dB, $m = 4$ and the power limiting factors are $c = 1 - 0.001$.

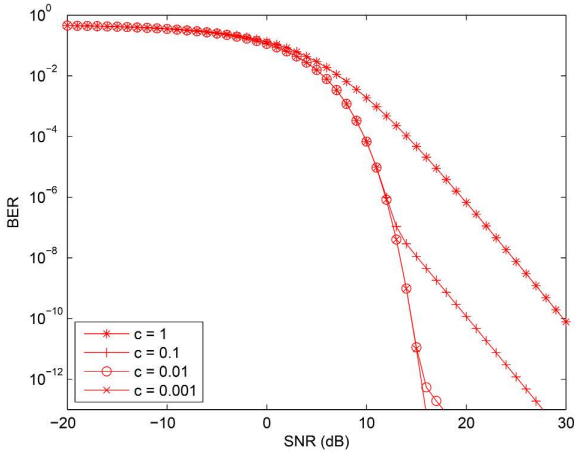

Figure 9. Theoretical results in the case of coherent binary transmission. Average BER of Nakagami fading channel against the average SNR, when the SNR of the measuring channel is $\gamma_0 = 30$ dB, $m = 4$ and the power limiting factors are $c = 1 - 0.001$.

noncoherent case, respectively. The average BER curves of Rician fading channel in coherent case are shown Fig. 4, when the fading parameter is $k = 10$, while Fig. 5 represents the average BER curves of Nakagami fading channel in coherent case, when the fading parameter is $m = 4$, against the average SNR. In these figures the SNR of the measuring channel is $\gamma_0 = 0 - 30$ dB and the power limiting factor is $c = 0.001$. A straightforward consequence of the proposed system is, when the SNR of the measuring channel increases and therefore the uncertainty of the fading channel gain estimation decreases, that the average BER reduces.

Average probabilities of BER curves of Rayleigh fading channel against the average SNR in case of coherent and noncoherent case are represented in Fig. 6 and Fig. 7. Fig. 8 shows the average BER curves of Rician fading channel in noncoherent case and Fig. 9 shows the average BER curves of Nakagami fading channel in coherent case against the average SNR. The fading parameters are the same as before ($k = 10$, $m = 4$). The SNR of the measuring channel is $\gamma_0 = 30$ dB and the power limiting factors are $c = 1 - 0.001$. Both in coherent and noncoherent case, the average BER reduces with the decrease of parameter c, which means with enabling higher transmission power the probability of bit error also decreases.

Note that the BER curve of the diversity is also represented. Because of using two channel (one for communication and one for the measuring) in our proposed system, it is better to compare the results against the diversity technique. The Fig. 2−Fig. 4 and Fig. 6−Fig. 8 show that it is possible to achieve better BER results instead of using diversity in some scenarios. That is true both coherent and noncoherent

cases. This is expected when the fluctuation of the fading is slower than the measuring time interval ($\overline{T}$) and feedback delay because this property enables higher γ_0 values.

One can assume a basestation (BS) with given transmission power, which is able to communicate to the cell edge, and a simple path loss model. It is easy to understand that in this scenario one can transmit information with a low transmission limiting factor c in the close range of the BS. The parameter c is growing proportionately with the distance. However, based on the results it is better to use measurement based feedback channel equalization technique in close range instead of diversity.

The numerical results are validated by simulations. The simulation process is implemented in MATLAB, and in each scenario 10^8 transmission was evaluated.

As mentioned before, we assume an errorless and fast (faster then the fluctuation of the fading) feedback channel, which is a strict requirement. The effects of the delay and the error in the feedback channel are complicated problems, they needs further investigations.

VII. SUMMARY

In this paper a new general analytical technique for exact error rate analysis of coherent and noncoherent binary wireless communication systems in the presence of nonselective slow fading, additive white Gaussian noise (AWGN) and using measurement based feedback channel equalization technique by estimating the fading channel gain in an independent noisy pilot (measuring) channel is proposed. It is shown with using measurement based feedback channel equalization, the proposed system is able to achieve BER gain against diversity technique in some scenarios, while the used channel bandwidth and the average transmission power is the same. The numerical results are validated by simulations.

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Guided Self-Organization for Edge ICT Fabrics

A. Manzalini[1]

Abstract— **This paper is arguing that technology advances and cost reductions in processing, storage and communications will determine a growing amassing of resources at the edge of current networks (i.e., in the distribution and access areas, up to end Users premises). This trend, intertwined with new emerging paradigms such as Software Defined Networks, will impact deeply the evolution future networks and services, enabling the deployment of novel flexible architectures capable of creating a galaxy of new ICT business opportunities. It is argued that the sheer number of nodes, devices and smart systems being deployed at the edge will create a sort of distributed "fabric" offering an enormous processing and storage power. On the other hand, the level of complexity and dynamism of said "fabric" will pose challenging requirements for the orchestration and management of edge resources, which could be faced by deploying a sort of bottom-up self-organization meeting classical top-down management approaches.**

Keywords-component; Autonomic, Self-Organization, Edge Networks, SDN, NfV, Standard Hardware, Future Networks.

I. INTRODUCTION

The term "fabric" has been used in the past to refer to a distributed computing system consisting of loosely coupled storage, networking and processing functions interconnected by high bandwidth links. The term has also been used to describe a flat, simple intra data centres network optimized for horizontal traffic flows, mainly based on a concept of "server-to-server connectivity". In this paper, it is argued that the edge (i.e., in the distribution and access areas of current networks, up to end Users premises) is going to become a sort of "fabric", i.e., a distributed platform consisting of loosely coupled processing storage and networking pervasive resources interconnected by wired and wireless link.

In particular, it is argued that technology advances (e.g., standard hardware performance, embedded communications, device miniaturization, etc.), and the related costs reductions, will determine such a large amassing of resources at the edge of current networks that, if proper managed, will be able to offer an enormous processing and storage power, at low costs.

Actually, "intelligence" has already started moving towards the edge since a few years, and it appears very probable that in the next few years the trends technology performance vs costs will allow a radically change of paradigm: from having a network of services to applications made available by a plethora of (small) Telco-ICT Players.

This will impact dramatically future networks evolution (not only at the edge, but even in the core segment), allowing not only cost-savings and QoS improvements, but even creating new business opportunities. Actually, technology and business developments will be more and more strictly intertwined in the future. Certain technologies and solutions will be adopted not only if advantageous (e.g., reducing costs) and trusted but also if they will enable desired business ecosystems (with the related foreseen business models); on the other hand, newly designed ecosystems will look for enabling solutions and technologies capable to bring them into reality. Metaphorically, it will be like in Nature, where evolution select the winning species: the winning ICT services will succeed, grow, and promote further investments, while losing ideas will fade away.

In this perspective, it will be strategic for current and future Players to explore the several challenges and opportunities offered by the exploitation of the edge "fabric" potentialities (e.g., in terms of QoS improvements, cost savings and new business models).

In fact, the edge domain is arguably the most active and critical segment of today's networks, in terms of innovation, strategy, and investment. Services and traffic dynamics will be more and more in the hands of Users (and by end Users it is meant not only people by also machines, smart objects, appliances and any device which is attached to the network at the edge). Nevertheless, the growing level of complexity and dynamism of said edge fabrics of resources will pose challenging requirements, from the management and control points of view, which will be covered only by deploying automatic and autonomic capabilities to enable a sort of guided self-organization in the edge fabric.

This should be seen in comparison with the current "network ossification" which is hampering innovation. In fact, traditional centralized processes (which worked perfectly in the past) are now creating a lot of limitations for the development and deployment of new network functionality, services, security designs, management policies and approaches, and other elements that are essential to cope with the increasingly challenges of future ICT networks and services.

One concrete example is represented by the number of middle-boxes [1] deployed in current networks: not only these nodes are contributing to the "network ossification", but also they represent a significant portion of the network capital and operational expenses (e.g., due to the management effort that they require). Basically, a middle-box is a stateful node supporting a narrow specialized network functions (e.g., layer 4 to 7); it is based on purpose-built hardware (typically closed and expensive). Examples of said functions are Wide Area Network (WAN) optimizers, Network Address Translation (NAT), performance-enhancing-proxies, intrusion detection and prevention systems, any sort of firewalls, other application-specific gateways, etc. Transforming fully in software these middle-boxes would determine several advantages, such as cost savings and increased network flexibility.

Emerging paradigms such as Software Defined Network (SDN) [2] and Network function Virtualization (NfV) [3], are likely to offer the opportunity to develop, fully in software, middle-boxes' network functions, and to allocate them dynamically according to Users' needs and Providers' policies. Some of these network functions are already available today in open source software and, in principle, could be executed as applications on Virtual Machines (VM) running

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standard hardware servers (as the ones available in Data Centres for provisioning Cloud Computing services). There are open source implementations of firewalls, load balancers, proxies and caches, monitoring and measurement, intrusion detection, and ubiquitous NAT. Even if today there are still some concerns about the performance of network functions fully developed in software and running on standard hardware, performance gap (with respect to purposed-built hardware solutions) is decreasing rapidly. Even today performance can be improved by utilizing hardware accelerators or by running multiple instances of the software (utilizing multiple processing elements).

As such, as an example, it is argued that will be possible allocating and executing said network functions in the edge fabrics, where an incredible amount of processing and storage resources are progressively accumulating. This will bring several techno-economic advantages, even to traditional Network and Service Providers, if they will be able to capture and adapt to the coming shift of paradigm.

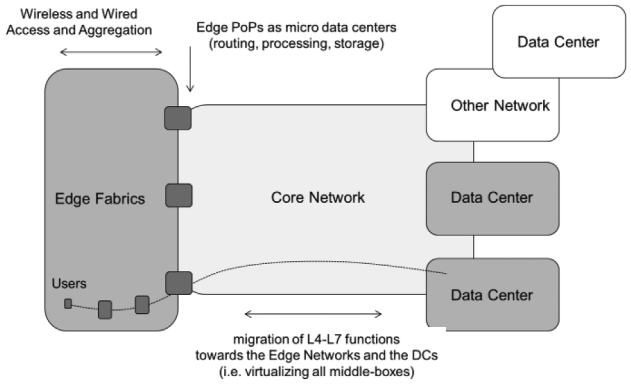

Fig. 1. Edge Fabrics

The outline of the paper is the following. In Section II provides some considerations about how approaching constrained optimization problems using the principles of statistical physics (e.g., in analogy with the symmetry breakings phenomena). Sections III makes a brief summary of the prior art about autonomic systems. Section IV describes the scalable node concepts and the overall functional architecture of the Edge ICT Fabrics. Finally, Section V gives the conclusions and discusses recommended future activities.

II. CONTROL OPTIMIZATION AND SYMMETRY BREAKINGS

In the near future the edge of communications networks will be composed by such a sheer number of resources that it will look like large scale distributed systems, i.e., a sort of fabric. As known, there are strict analogies between large scale systems and statistical mechanics. In this section we'll explore how statistical mechanics and autonomic principles can help us in deploying a guided self-organization in the Edge ICT Fabric.

As well known, statistical mechanics provides a framework for relating the microscopic properties of individual atoms or molecules to the macroscopic properties of materials. In other words provides a molecular-level interpretation of macroscopic thermodynamic quantities such as work, heat, free energy, and entropy. For example the behavior of a gas (e.g., modelled by the state equation) can be described at the microscopic level in terms of the position and velocity of each molecule, which appear as random processes. Local random behavior of the molecules causes the gas as a whole to solve a large scale constrained optimization problem.

Similarly the behaviour of electrons in an electrical network can be described in terms of random walks. This simple description at the microscopic level leads to rather sophisticated behavior at the macroscopic level: for example, patterns of potentials in a network of resistors is minimizing heat dissipation for a given level of current. Again this is like to say that the local random behavior of the electrons causes the network as a whole to solve a large scale constrained optimization problem.

Moving to small living entities, a termites colony can be seen self-organized ecosystem. We can imagine that each termite has its own utility functions (for example concerning aspects related its survivability): evolution selected those behaviors capable of maximizing said utility functions. Termites are interacting each other, and with the environment, thus cross-influencing their behaviors and having an impact on the environment. Again this is like saying that the termites' behaviors and cross-interaction allow solving a global utility i.e. large scale constrained optimization problems.

In summary, one may say any large scale (eco)systems tends to move from the state with higher energy (i.e., higher cost) to the state with lower energy (i.e., lower cost); local minima of this functional are usually related to the stable stationary states (functional minimization). Indeed, maximize profits, minimize costs, minimize the loss are typical economics problems, which can be mathematically modelled as constrained optimization problems.

It is argued that the same approach could be taken for designing and operating an highly flexible network architecture at the edge capable of self-adapting dynamically to changing conditions: the guided self-organization will become a property emerging from the interactions of nodes local behaviours, solving constrained optimization problems.

A typical approach in similar directions is looking for minimization (or maximization) of an objective function subject to constraints on the possible values of the independent variables. For example "Layering as Optimization Decomposition" [4], [5] integrates the various protocol layers into a single coherent theory, considering them as carrying out an asynchronous distributed computation over the network to implicitly solve a global Network Utility Maximization (NUM) problem.

Since then, many research studies have been carried out on distributed network resource allocation using the language of NUM. These efforts have found many applications in network resource allocation algorithms and Internet congestion control protocols, e.g., [6], [7], [8], [9]. For example, the TCP/IP protocol can be seen as an example of an optimizer: its objective is to maximize the sum of source utilities (as functions of rates) with constraints on resources. In fact, each variant of a congestion control protocol can be seen as a distributed algorithm maximizing a particular utility function. The exact shape of the utility function can be reverse-engineered from the given protocol. Similarly, other recent results also show how to reverse engineer Border Gateway Protocols (BGPs) as a solution to the Stable Path Problem, and contention-based Medium Access Control (MAC) protocols as a game-theoretic selfish utility maximization.

Also cross-layer interactions can be characterized by viewing the process of network layering as the decomposition of a given NUM problem into many sub-problems. These sub-problems are then "combined together" by certain functions of the primal and dual variables [5].

Normally maximization/minimization of complex functions (or functionals) are achieved with metaheuristics. On the other hand,

these approaches are not that scalable (and quickly converging) for highly distributed systems composed by huge amount of interacting nodes, which is the case for the edge fabrics.

This paper adopts another perspective, typical of statistical physics, which is achieving guided self-organization as a property emerging from the interactions of nodes local behaviours.

Let's imagine an edge fabric where a number of nodes are interacting and their interactions are depending on a set of control parameters. The performance of a swarm of nodes can be described by a reward associated to an average over the nodes states and over time. This is typical problem considered in statistical physics when dealing with the symmetry breakings[2] in large ensembles of interacting particles.

Mathematically speaking, symmetry is characterized by the invariance of some mathematical object under some transformation. For example, a parabola $y=x^2$ is symmetrical with respect to the y-axis, since it is invariant under the transformation that takes the variable x and transforms it into –x. In classical physics, symmetry breakings imply conservation laws: for instance, translation invariance implies momentum conservation, while rotational invariance implies angular momentum conservation. There are many systems that exhibit symmetry breakings phenomena: Bose–Einstein condensates, superfluids, superconductors, ferromagnets, anti-ferromagnets, crystals, and, according to the Standard Model, particles.

In the context of this paper the term symmetry breaking indicates the emergence, in swarms of interacting nodes, of a guided self-organization leading to solve large scale constrained optimization problems. A key question is if and how distributed control strategies can break the symmetry of the interactions in a guided way.

As a simple example, imagine introducing into the nodes automatic and autonomic features in terms sets of "controllable" local rules, making the nodes able to learn to compute input-output data mapping with desired actions or properties (local rules means rules capable of changing for example the "strength" of the interconnections of a node in the immediate neighbourhood; moreover this would be in line with the Hebb's postulate of learning).

A. Example of Symmetry Breaking in an Edge Fabric

Let's consider a wireless network composed by a large number of entities. It can be demonstrated mathematically that for a certain number of nodes, and for a critical communication range (i.e., the control parameter) the probability that the network is fully connected shows a sudden transition 0-1 (e.g., that could be seen as a phase transition). This is an example of symmetry breaking under guided with the control parameter, i.e., communication range.

The theoretical capacity of the network is proportional to the square root of the network size (number of nodes): e.g., one million nodes with available bandwidth of 1 Mb/s can reach a total capacity on order of Gb/s if the control parameter is properly tuned.

Let's imagine now that Users may wish sharing not only the wireless bandwidth but also their local storage and processing resources: the fabrics, in principle, could abruptly provide an enormous capacity. In fact, again, for a certain number of nodes, and a critical level of resource sharing, the overall throughput of the network shows a sudden transition like a symmetry breaking (in this case the control parameter could be the level of incentives to Users – or even to other Providers - to encourage to share their physical resources).

Several start-ups are already offering today storage and disaster resilience services using decentralized and distributed virtual resources, shared by Users. So, indeed, the concept of harnessing idle resources is starting to be extended also to the processing idle power distributed at the edge, up to the Customers' premised. Examples of provisioned services will be CDN-like services, content sharing, aggregation, transformation, data collection, etc.

On a large scale, nevertheless, this would require guided self-organization capability for properly orchestrating said local idle storage and processing resources when executing and provisioning network functions and other services.

B. Example of Use Case

A Network-Service Provider may want to provide Users' with the features that personal data (e.g., stored in edge micro Data Centres) and applications (e.g., executed by local edge resources) are following them seamlessly when they are moving from one network attachment point to another one (even when this implies the move to other fabrics crossing the Core network).

In other words, it should be possible to move data and VMs executing services seamlessly with no impact on QoS/QoE perceived by the Users. It should be possible, also, for security or other policies to follow logically specific network applications (e.g., running on VMs). These features could be extended to data and services associated to Users in order to build distributed virtual data centers at the edge (this is an ideal service, for example, for Universities, Enterprises, etc.), provided at costs which are a small fraction of traditional cloud computing services.

Let's imagine now an event (e.g., Olympic Games) where a crowd of people is converging towards a certain venue. The aggregation of a crowd of Users in space and time can be seen as a symmetry breaking event. The Network-Service Provider should make sure that the network and service fabrics is following opportunistically the same symmetry breaking by dynamically moving data and VMs to provide Users with the requested ICT services with the expected QoS. This can be achieved through a guided self-organization of the Edge ICT Fabrics.

III. PRIOR ART ON AUTONOMICS

There is an impressive number of publications and initiatives investigating these issues, most of which relate to architectures and component models, offering the basic building blocks with which to create autonomic self-* behaviors. This section presents a brief and incomplete overview of these works.

IBM, as part of its autonomic computing initiative [10], has outlined the need for current service providers to enforce adaptability, self-configuration, self-optimization, and self-healing, via service (and server) architectures revolving around feedback loops and advanced adaptation/optimization techniques. Driven by such a vision, a variety of architectural frameworks based on "self-regulating" autonomic components have been proposed [11], [12], [13] based on the common underlying idea to couple service components with software components called "autonomic managers" in charge of regulating the functional and non-functional activities of components.

In Autonomia framework [14], the autonomic behaviour of a system and its individual applications is handled by so-called mobile agents. Each mobile agent is responsible for monitoring a particular behavior of the system and for reacting to the changes accordingly.

[2] This phenomena occurs if a macroscopic state of the system is not symmetric with respect to the symmetry of the interactions in the system.

A slightly different approach is provided by the AutoMate framework [15]. Similar to Autonomia, autonomic behavior in the AutoMate framework is handled by the agents and is implemented in the form of first order logic rules. Agents continuously process these rules and policies among themselves and perform the desired actions.

In [16], FOCALE architecture is based on mapping business level system constraints down to low-level process constraints in an approach called policy continuum [17]. This policy-based approach for specifying autonomic system behavior allows network administrators to specify business level policies for network management (using natural language), for example, defining different internet connection bandwidth rates for different users, SLA, QoS policies etc.

In [18], the Autonomic Communication Element (ACE) model is described. ACEs can autonomously enter, execute in, and leave the ACE execution environment. In general, the behavior of autonomic elements is typically provided in relation to the high-level policies that define the element's original behaviour [19]. Within the ACE model, such policies (called plans) are specified through a number of states, along with the transitions that lead the ACE execution process from one state to another. Plans distinguish between the ACE's "regular" behavior, which is its behavior when no events undermining the ordinary execution occur, and the "special cases" that can occur during the plan execution process and which could affect the regular ACE execution process. If such occurrences are foreseen, the ACE behavior can be enhanced with rule modification specifying the circumstances under which the original behavior can be relinquished, along with the new behavioral directions to follow.

A very similar endeavor also characterizes several research efforts in the area of Multi-Agent Systems [20]. Multi-agents represent (de facto) the types of autonomic components which are capable of self-regulating their activities in accordance with some specific individual goal(s) and, by cooperating and coordinating with each other, according to some global application goal. However, it is worth emphasizing that that Multi-Agent Systems does not imply an autonomic behavior per-se. At the level of internal structure, Belief Desire Intention (BDI) agent systems, as implemented in agent programming systems like Jadex, JACK or Jason or in the context of the Cortex project [21], propose the use of intelligent agents to deal with autonomic and context-aware components. At the core of this model there is a rule-based engine acting on the basis of an internal component state that is explicitly represented by means of facts and rules [22], [23]. At the level of multi-agent systems and their interactions, agents are generally expected to discover each other via specific agent-discovery services, and are supposed to be able to interact.

It should be mentioned that RTD activities on autonomic networking and self-managing networks have reached a maturity level so to start moving results toward standardization of architectural principles of the Self-Managing Future Internet. This is done in the Industry Specification Group (ISG) on Autonomic network engineering for the self-managing Future Internet (AFI), under the auspices of the European Telecommunications Standards Institute (ETSI). Specifically the AFI architectural reference model is a set of fundamental design and operational principles, describing the functions, processes, and interfaces, and so it provides Decision-making Elements (DEs), responsible for autonomic management and control of network resources [24].

Common to most of the proposed approaches (both those based on autonomic components and multi-agent systems) is the existence of a traditional middleware substrate to implement discovery and interactions between components or agents. On the other hand, none of the above approaches seems to address the problem of globally re-thinking ubiquitous networks as complex environment with emerging properties.

In [25], [31] a number of results and proposals have been presented about self-aware networks, i.e., networks capable of exploiting self-adaptiveness. Several questions have been addressed such as scaling, security, reliability and mobility.

The novelty introduced by this paper is providing a simple architectural model, based on three layers, for a guided self-organization of resources ubiquitously distributed in the edge of current networks. The vision is that edge resources can flock together and create a sort of fabric collecting many individuals that form large organized communities, where services can be spread virally.

IV. AN ARCHITECTURE FOR GUIDED SELF-ORGANIZATION

We are arguing that the edge fabrics will be composed by a sheer number of nodes devices, and smart objects which are flocking, being interconnected by wireless and wired links. The complexity, deriving from the number and dynamism of the interconnections, requires that each node of the fabric to be both sensitive to the context variations and capable of reacting "autonomically" in order to self-adapt to changing conditions.

Figure 2 is showing the concept of an edge node which could scale from a Customer Premises Equipment up to an Edge PoP. In particular, an Edge PoP can be seen as the future evolution of current edge routers, i.e., a sort of micro-data center at the border between access-aggregation (edge) and core networks.

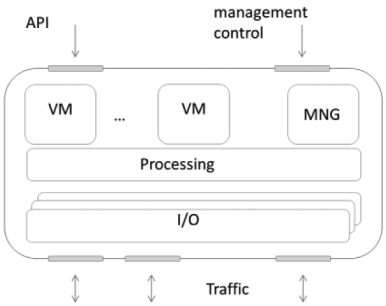

Fig. 2. Example of scalable node concept

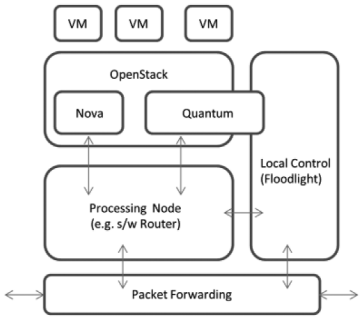

Fig. 3. Another example of node (Edge PoP) concept (with Open Source Software and Standard Hardware)

As a further example, figure 3 is showing, for example, a possible implementation of the Edge PoP, in terms of available open source software (e.g., OpenStack, Floodlight) and standards hardware (e.g., x86) for packet forwarding. This type of node could offer network

functions fully developed in software and executed in VMs. Moreover the node could be programmable offering sets of APIs related to control parameters steering towards self-organization.

In principle, these edge nodes can be seen as Distributed Event Systems (DES), whose states are time-evolving as events occur. From a theoretical viewpoint, many approaches have been proposed to model DESs, most notably finite state machines, Petri nets and generalized semi-Markov processes. Among these models, Finite State Machines (FSM) represents, probably, the computation model that is the most straightforward means to control performance indicators. FSM provides for a good understanding of the predictable problems such as controllability, co-observability, normality, decentralization, and non-determinism.

Therefore each node can be modelled as a network of interacting FSMs with programmable control points. Interestingly, non-determinism in FSMs is represented by a choice of states where the optimal action is yet to be decided and where it can be learned, with reinforcement learning. This is for further study.

From a purely functional perspective, a node could be seen as consisting of a set of services, leveraging the concept of Self-Managed Cell architecture reported in [32]. For example, the discovery service discovers resources and components being part of the node and the other nodes entering in the communication range (each single node is clearly designed for interactions). The policy service is in charge of managing the policies specifying the node behaviour. A publish/subscribe event bus is used for interaction between node' components and for distributing events triggering policies.

The overall fabric architecture is structured into three layers, in charge of actuating three different kinds of behavior:

- Automatic behaviour: this capability is achieved with fast pre-defined reactions for self-adaptation to predefined contexts and can be designed by means of automatic control-loops modelled with deterministic FSMs and deployed into edge nodes;
- Autonomic behaviour: this capability is responsible for local adaptation and it is achieved by exploiting unsupervised learning capabilities. The layer can be designed with ensembles of deterministic and non-deterministic FSMs and reinforcement learning methods deployed into edge nodes;
- Self-organization emergent behaviour: this is an emergent capability achieved through the orchestration of local reactions (e.g., through activation-deactivation of rules) by means of local context information diffused for reaching the global goals. It is a sort of "guided" reaction-diffusion process of context information.

In other words, self-organization emergent behaviour could be achieved by developing a sort of global coordination field (i.e. a global context), injected by nodes (and potentially control points) in the network and autonomously propagating. All nodes are interacting with each other and with the environment by simply generating, receiving and propagating distributed data structures (e.g. tuples), representing context information.

This field is providing the nodes with a global representation of the situation of the fabric (to which they belong). This coordination field is immediately usable: a node is moving in this field like an object is moving in a "gravitational" field. Environmental dynamics and nodes' local decisions will determine changes in the field, closing a feedback cycle. This process enables a distributed overall self-organization.

As mentioned coordination field can be made of tuples of data which can be injected and diffused by each node. Local reading of these tuples of data (e.g. through pattern matching) can trigger local self-adaptation behaviours.

A simple event-based engine, monitoring configurations and the arrival of new tuples, reacts either by triggering propagation of other tuples or by generating events. A number of open source applications are available on the web to implement node primitives and local autonomic behaviours.

V. CONCLUSIONS

This paper has proposed the vision whereby recent advances in standard hardware technologies and open source software are creating the conditions for exploiting highly innovative network architectures, mainly at the edge of current networks.

As a matter of fact, the sheer number of nodes, devices and systems being deployed at the edge, up to Users' premises, are offering an enormous processing and storage power. It is argued that exploiting these resources, closer to the Users, to execute network functions and services will bring several advantages, both in term of improved performance and cost savings (e.g., determined by the removal of middle-boxes). Moreover, the exploitation of these principles at the edge of current networks will transform this area into a fertile ground for the flouring of new ICT ecosystems and business models.

The paper has also presented the concept of an edge node (based on standard hardware) which could scale from a Customer Premises Equipment up to an Edge PoP. In particular, an Edge PoP can be seen as the future evolution of current edge routers, at the border between the core and the edge fabrics. The overall functional architectures of an edge fabric has also been presented showing the exploitation of programmable automatic and autonomic capabilities, leading to the emergence of the guided self-organization.

Preliminary simulations and experiments are showing the feasibility of this vision. Next steps will continue this and will include also techno-economic analysis, aiming at simulating the impact of diverse cooperation-competition strategies in guided self-organization.

Lessons learnt, up today, is that tremendous technology advances are indeed making possible to develop L3 to L7 network functions (almost) fully in software (e.g., in Virtual Machines) and to allocate and move VMs dynamically on distributed resources. This trend is accelerating day by day. In the short-medium term (e.g., in five years) these trends are likely to create "tipping points", beyond which new equilibria and new ecosystems will emerge in the Telco-ICT.

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Systematic Analysis of Time Series - CReMIT

Zoltán Pödör[1], Márton Edelényi[2], László Jereb[2]

***Abstract*—One of the problems frequently arising in connection with the study of time series is the most thorough examination of any correlations between them. In the case of time series with periodicity, study of the effects of periods with time shifting, delayed and varying length can be also examined. We present a data transformation procedure that allows more intensive studies by the systematic expansion of the basic data set due to the applied special window technique (CReMIT). To apply it in the practice, the method has been integrated in a uniform analyzing process that includes operations from the preparation of data lines for analysis, via their systematic transformation to the implementation of the analyses. The modular structure of the system provides high flexibility due to which the process can be suitable for the study of relations between time series of any type in practice by using the adequate expansions.**

***Index terms*—time series, systematic extension, CReMIT, data transformation, analyzing process**

I. INTRODUCTION

Searching for relations between the time series is a major area of statistics and data mining. A vast number of techniques are available and among them correlation and regression analysis [15], [20] defining connections between one or more independent and dependent variables are the most frequently used ones. At the same time the success and completeness of the studies can be significantly affected by the sphere of the involved dependent and independent parameters and in addition, the applied methods of their use in the analysis process. For example, the Principal Component Analysis (PCA) [1] or cluster analysis [11] can be suitable for the reduction of dimensions by combining the relevant variables.

In certain steps of the analysis generally only a specific slice specified by a window is used instead of the full range of the available time series. In the case of data lines of proper length, the temporal change of the connections can be examined using the forward and backward evolution techniques and moving intervals [3]. The evolution technique means, in fact, that the width of the applied window increases by one in each iteration without changing its starting point. In the case of moving intervals, the length of the examined interval is fixed in a suitable way and the starting point is moved forward by one cycle in every iteration step.

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The window technique is used also in many other statistical procedures such as simple moving averaging, cover-up of events in time series [19] or segmentation procedures [8], [12] used also in the mining of time series. In all mentioned cases, an actual transformation or observation function is taken into account over the defined window. These procedures are characterized by the fact that only the width of the examined window or the starting point of the window changes in the individual iterations. The fuzzy time-series includes special window based techniques. These time series can be defined for example by differential equations. To predict the value at certain point $t + P$ in the future we want to use known values of the time series up to the point t in time. The standard method for this type of prediction is to create a mapping from D sample data points, sampled every α units in time $\big(x(t-(D-1)\alpha); \dots; x(t-\alpha); x(t)\big)$ to a predicted future value $x(t+P)$. The D, P and α values are usually defined by the user.

The window techniques can be used not only during the breakdown of the whole examined data line into intervals but also in a more specific meaning in the case of periodic time series. Periods can be often inherently assigned to time series used in studies relating the observations of the natural environment. Let's think of the temperature, rainfall, atmospheric pressure, tree growth, reproduction etc. data for which e.g. annual cycles can be defined. The relevant studies often require the creation of windows covering more than one previous cycles and having a varying width within a certain period and containing given aggregated data sets so that we can study their effects.

In our researches, basically we examined problems relating time series of forestry nature, with a special regard to the typical climate parameters on the forestry variables (tree growth, healthy conditions, lighttrap data). In the literature there are a great number of window techniques used. Let's take into consideration the analysis of the effects of the monthly rainfall and temperature data on the annual tree growth [7], [9], [10], [13], [14]. Moving window [5], [18], [22] and evolution techniques [2], [3] are often used to show the varying effects of the climatic components, and specially developed periodic data are also used [4], [17], [21]. However, they are created generally on experimental observations, and are not intended to global use.

Based on the above methods, a systematic window concept can be created by using their beneficial properties. The solution combines the essence of moving intervals and evolution techniques, the systematic movement of the windows and the systematic creation of windows with different widths for the individual steps. The procedure ensures the combination of the

time shifting and width values of the windows in a single process, significantly widening the sphere of the analyzing possibilities. The method has been basically developed for the solution of forestry related problems but it can be applied to any other periodic time series as well.

The procedure is integrated in an analyzing process that includes preparation of the data, data transformation and analysis procedural modules. In view of the possibilities, these modules are independent and can be adjusted thereby the spectrum of analyses can be increased and widened. The transformation module (CReMIT: Cyclic Reverse Moving Intervals Techniques) widens the sphere of variables that can be included in the study by using systematic transformation of the basic data on the basis of the above window technique.

II. Data Transformation – CReMIT

Let there be a time series and its natural period is marked by P. The elements of the time series are stored in vector x. Let its first element be the chronologically latest element, and natural numbers will be assigned to the data accordingly.

$$x = \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix} \tag{1}$$

Let K $(1 \leq K \leq P)$ mark the starting point of the currently applied study, this is the Kth element of the vector. The time shifting (i) and width (j) values of the window applied on the time series are defined on the basis of this index. The minimal value of time shifting can be 0 $(i = 0)$, and the window width can be 1 $(j = 0)$. Using the periodicity of the time series the window defined in the above way will be periodically repeated, and the maximum cycle number (MCN) depending on the parameters and the length of the data line can be created. This MCN value defines the number of windows and the dimension of the transformed vector.

The starting and end point indexes of the windows created with the actual K, i and j values can be defined as $[K + i + l * P\,; K + i + j + l * P]$, $0 \leq l \leq MCN - 1$. Two temporal vectors are defined for the storage of the index values determining the limits of the windows using these parameters. Let us denote by:

$$index_b = \begin{pmatrix} K + i + 0 * P \\ K + i + 1 * P \\ \vdots \\ K + i + (MCN - 1) * P \end{pmatrix} \tag{2}$$

$$index_e = \begin{pmatrix} K + i + j + 0 * P \\ K + i + j + 1 * P \\ \vdots \\ K + i + j + (MCN - 1) * P \end{pmatrix} \tag{3}$$

By using the above indexes pre-defined transformation function TR can be applied on the elements of the individual windows.

$$tr\_x_{K,i,j} = \begin{pmatrix} TR(index_b[1]; index_e[1]) \\ TR(index_b[2]; index_e[2]) \\ \dots \\ TR(index_b[MCN]; index_e[MCN]) \end{pmatrix} \tag{4}$$

Based on the starting point K $(1 \leq K \leq P)$, the maximum time shifting value I $(0 \leq i \leq I)$ pre-defined on the basis of the task, the maximum window width J $(0 \leq j \leq J)$ and all the potential $tr\_x_{K,i,j}$ transformed vectors a systematic analysis procedure can be generated.

The value of the maximum cycle number, i.e. the dimension of the transformed vector is of significance in the individual iteration steps. In relation to vector x, this is determined by (MCN_x), the last (chronologically the oldest) element of the first window currently examined in a given iteration, $(K + i + j)$th element and the value of P period:

$$MCN_x = \left[\frac{n-(K+i+j)}{P}\right]+1, \tag{5}$$

where [] is the entire function.

The above transformation procedure generalizes the window techniques presented in the introductory chapter. Methodologically, it combines their beneficial properties, therefore it majors them. On the one hand it is able to change systematically the window width used in the evolution technique and to change systematically the starting point determining the moving intervals on the other hand. The advantage of CReMIT against these methods is that when the two principles are combined it can simultaneously and perfectly handle the windows with combined starting points and widths.

If the time shifting i is considered fixed and the window width is changed $(0 \leq j \leq J)$ the principle of the evolution technique is used: the window width is increased by one in each iteration step with a given starting point. If the window width is considered fixed with a given value j and the time shifting i is changed $(0 \leq i \leq I)$, then the method of moving intervals is implemented: the window width is fixed, and the window is moved forward by one in each iteration. With the choice $i = 0$ and $j = 0$ parameters, the relation between the actual $K, K + P, K + 2P$ etc. dependent and the independent variables of the same indexes are investigated. If $P = 1$, then with the given time shifting and window width values the original evolution and moving interval techniques are implemented for non-periodical time series.

The fuzzy time series techniques mentioned in the introductory chapter resembles to the CReMIT method, but they are able to implement only a part of CReMIT. These techniques use a starting point t, a time shifting α, but use only single elements, do not create windows with different width to define transformed time series.

III. THE ANALYSING PROCESS

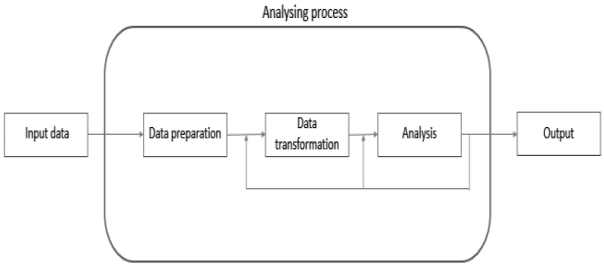

Fig. 1. The analysing process

The CReMIT transformation procedure has been established for the systematic study of more complex relations between periodic time series. The analyzing process built around the transformation procedure allows the use of the complete preparation-transformation-analysis process as a single unit, while the modular structure provides high flexibility in relation to the variables involved in the study, their transformed derivatives and the various analysis methods too.

The first main module is the data preparation that makes the raw data suitable for the integration into the transformation module. This involves not only the traditional data preparation (data cleaning, handling missing data) but also the combination of the raw data by time or by other aspects, or its breakdown, for example conversion of event based detections into identical time units. This data preparation allows us to organize the data into relevant periods as well.

The second module CReMIT is the transformation module that includes the essence and novelty of the procedure. This block is responsible for the systematic preparation of secondary data sets (time series) based on the transformation technique presented in the previous section.

The third module of the process receives data lines prepared during the transformation and carries out the pre-defined analysis procedure. The analysis performs basically the testing of connections between the time series including most frequently the correlation and the regression analysis.

The modules of the process are superimposed on each other but on the other hand, they are still independent to a certain extent and this feature provides significant flexibility and the possibility of combining and expanding the preparation, the transformation and the analysis methods. Next examples illustrate the possibilities of the use and the expansion of the process.

A. The Application of CReMIT

The basic method offers a number of development and expansion possibilities either in view of transformation functions used in the analysis module or of expansion to several variables. Transformation function TR used in the module can be a simple elemental conversion, for example average, sum, minimum, maximum. However, more complex other possibilities than the elementary functions can be also defined when for example some weight functions (which is exponential so that the effects of the chronologically older elements are exponentially reduced, or even other weighs considering special aspects can be defined) or non-linear functions are applied on the elements of the windows. The use of binary weight factors is a special application case that defines non-continuous windows. In addition, the method offers also the possibility when the transformation function is used not on all elements of the designated window but only on its elements meeting one or more given conditions.

The operation of the transformation module was presented in connection with vector x in general. Therefore it is a natural possibility of use when the transformation procedure is applied on the single independent parameter with the static dependent variable. This allows us to study the effects of the data segments of the examined independent variable having different lengths and time shifting on the dependent parameter.

Moreover, the procedure can be simply expanded to the dependent or more independent variables too. Applying it to the dependent variable we can analyze the effects of the independent parameter(s) on the various periods of the dependent parameter. Furthermore, the expansion to several independent variables makes the system also suitable for the implementation of analysis with multiple variables. If the periodicity of the different vectors is different or if we want to define various I and J values for them then all the applied vectors must be taken into consideration for defining MCN in the given iteration step (if the applied analysing method requests identical vector dimensions):

$$MCN = min\{MCN_{x1}; MCN_{x2}; \dots; MCN_{xw}\}, \qquad (6)$$

where w indicates the number of variables involved in the study, and MCN_{xm} $(1 \leq m \leq w)$ defines the maximum cycle number for vector x_m $(1 \leq m \leq w)$. In addition, the temporal vectors (w vector pairs) storing the starting and end indexes of the windows must be separately defined for each variable, and the transformation function TR can be also defined differently by any vectors.

The transformation procedure offers a number of uses and expansions in relation to either the individual handling of variables involved in the study or the applied transformation functions TR.

B. The Analysis Module

The transformed vectors prepared by the CReMIT module form the input for the analysis module. The available analysis procedures are preliminarily implemented by the user, and it is important to mention that the analysis module only uses the results of the transformation, and therefore, it is totally independent from the operation of the transformation module.

Let us suppose that a single variable correlation and regression analyses are carried out with transformations applied to the independent variable. In this case the transformation step prepares a 2 dimension matrix output depending on the value of parameters applied to the independent variable in the analyzing module, where the lines indicates the current time shifting and the columns indicate the window widths. The individual cells contain the results

obtained with the given time shifting i and window width j. Each cell contains a simple correlation coefficient or a more complex data structure depending on the nature of the examination. In order to provide more useful information for the users the test of the correlation significance is performed. Based on new statistical approaches [16] the effect size value is a nice measure for quantifying the difference between two groups on a common scale. But it measures only the effect size, not the sign of the effect. In this paper we used the correlation test based on t-test, which depends on the length of examples, because we have to know the sign of the effects too

Table 1 shows the results of the single variable correlation analysis. In the cells of the table the correlation coefficients can be seen only in those cases when the significance test was positive for the given set of data.

TABLE 1
OUTPUT MATRIX (EXAMPLE)

		J					
		0	***1***	***2***	***3***	***4***	***5***
I	***0***	0.43					
	1				0.65		
	2		0.54				0.5
	3					0.71	
	4	0.76			0.32		
	5			0.68			0.56

The applied analysis method in the analysis module can be simple linear correlation analysis, but in this module other more complex nonlinear methods can be applied too.

The software frame is implemented in the open source R (R 2.15.2. version) environment and the implemented elementary TR functions are the mean, sum, minimum and maximum ones. The default analysing procedure is the linear correlation analysis. The values of the applied parameters (K, I, J) depend on the actual problem. If the transformation procedure is expanded also to the dependent or to several independent variables the dimension of the output matrix will increase accordingly.

IV. CASE STUDY

The Forestry Light Trap Network has been operating in Hungary since the beginning of the 1960s which is a long period even internationally. The catching data of the various insects and butterflies are yearly summarized. The monthly precipitation sum and the average temperature are the studied meteorological parameters. This is explained by the fact that these two components are generally available in that breakdown, and the obtained results can be expanded also to other areas.

The purpose of the studies was to examine the dependence of the population dynamics of the selected species on the climate parameters. The time series of 23 catch places and 9 insect populations with different time length were examined. The analysis comprised the weather effects of the subject year and of the previous year by applying the CReMIT transformation procedure to monthly precipitation sum and average temperature data from April of the previous year to August of the actual year in a maximum length period of 6 months ($K = 5$, the index of month August, $I = 16$ and $J = 5$). The notation of previous year is p and the actual year is a. The resulting statistical correlations were analyzed in view of many aspects.

First the insect species and catch places were examined separately. Therefore we got 9*23=207 separate tables, with statistically significant correlation values ($\alpha = 0.05$). The relationships – concerning the given species and catch places – can be examined one by one based on these tables.

TABLE 2
SIMPLE RESULT TABLE OF ONE SPECIES AND CATCH PLACE

K=5		J					
		0	***1***	***2***	***3***	***4***	***5***
	0		0.428	0.519	0.576	0.423	0.416
	1		0.505	0.605			
	2	0.482	0.557				
	3	0.503					
	4						
	5						
	6						
	7		-0.487	-0.432			
I	***8***	-0.459					
	9			-0.523			
	10						
	11						
	12						
	13						
	14						
	15						
	16						

In order to obtain a more overall view of the individual species the significant correlation values of all catch locations can be arranged in a single table. With the purpose of getting the most useful general relations we can define a threshold value k that defines the minimum number of catch places where the correlation is significant in the given time period, generated by the CReMIT procedure.

TABLE 3
ONE SPECIES AND ALL CATCH PLACES (K=3)

time intervals	Loc.1	Loc.2	Loc.3	Loc.4	Loc.5	Loc.6
p8-a2		-0.723	0.564		0.515	
p10	0.497			0.421	0.626	
p12	-0.580	-0.581		-0.459		
p12-a1	-0.580	-0.581		-0.487		
p12-a4		-0.732			0.469	-0.522
a1-a4		-0.747			0.502	-0.525
a5	0.519			0.503	0.485	
a5-a6	0.519			0.557	0.508	
a5-a7	0.570			0.605	0.649	
a5-a8	0.535			0.576	0.549	0.508
a6-a7	0.490			0.505	0.628	
a6-a8	0.500			0.519	0.530	0.560

In Table 3 the significant correlation values for one of the species in all possible locations and with threshold k=3 are depicted. These tables and results provide many additional examination opportunities, for example it is possible to identify similar catch places based on the correlation values and to analyze the reason of these similarities (maybe using some other parameters for the catch places). Using the significant time periods determined by CReMIT – multivariable analysis can be also performed and models for the catch data based on the climate parameters can be also derived.

V. SUMMARY/CONCLUSIONS

The study of the time series and the efficiency of the search for connections between them can be affected by the applied analysis methods and the sphere and use of variables involved in the study. The paper presented a transformation procedure CReMIT that supports the analysis of complex relations in a systematic way. Based on the systematic expansion of the width and time shifting of the windows applied to the variables, this will allow us to carry out more extensive studies than the previous, typically specific concepts. The method is implemented in an analyzing process, and it has been already used in practice on several data lines in forestry.

The independent parameters are often connected to climate or meteorology (precipitation, temperature, air moisture, blast, soil moisture, etc.) while the typical dependent variables are different measures of forestry, for example tree growth, healthy conditions, mortality, lighttrap data of pests and moths. Generally, the data lines show periodic properties and the identified correlations can provide information for experts to make scientifically supported decisions. Although our aim was to develop a method and apply for the given problems and not to derive professional forestry conclusions the applicability of the method to such problems has been shown by the investigations performed so far [6].

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The Piggy Bank Cryptographic Trope

Subhash Kak

Abstract— **This paper presents applications of the trope of the locked and sealed piggy-bank into which the secret can be easily inserted but from which it cannot be withdrawn without opening the box. We present a basic two-pass cryptographic scheme that can serve as template for a variety of implementations. Together with the sealed piggy-bank is sent a coded letter that lists and certifies the contents of the box. We show how this idea can help increase the security of cryptographic protocols for classical systems as well as those based on "single-state" systems. More specifically, we propose the use of a hashing digest (instead of the coded letter) to detect loss of key bits to the eavesdropper and use in communication systems where error correction is an important issue.**

Index Terms— **Cryptography, network security, multiparty communication, piggyback protocol**

I. INTRODUCTION

THE idea of locking a secret in a box and letting it be carried to the destination by an unreliable courier (Figure 1) (where it is unlocked by the recipient who has the key to unlock the box) is at the basis of most cryptographic protocols. This scheme assumes that the key has somehow been transported to the recipient in advance of the communication. The lock of the box is protected by placing a seal across it that ensures that it is not tampered with by the courier.

In the case of the use of this scheme in data communication, the key may be transmitted over a side channel. If the rate at which the key is transmitted over the side channel equals the data rate, then this constitutes the unbreakable one-time pad [1],[2].

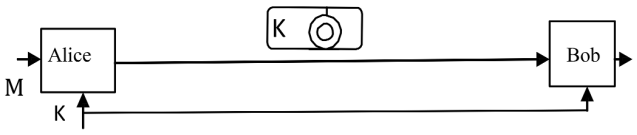

Figure 1. Sending a secret in a locked box (unlocking needs key K)

Another idea is that of the three-stage protocol (Figure 2) which can be used when the recipient does not possess a copy of the key. This requires that both parties use locks and it is assumed that the locks are protected by tamper-proof seals of the two parties. In this protocol Alice puts the secret in a locked box which is transported to Bob who puts his own lock on the box and sends it back to Alice who unlocks her lock and resends the box to Bob who then unlocks his lock. This protocol ensures that both Alice and Bob can check that their locks have not been tampered with. Amongst other applications, this idea is at the basis of the three- stage quantum cryptography protocol [3].

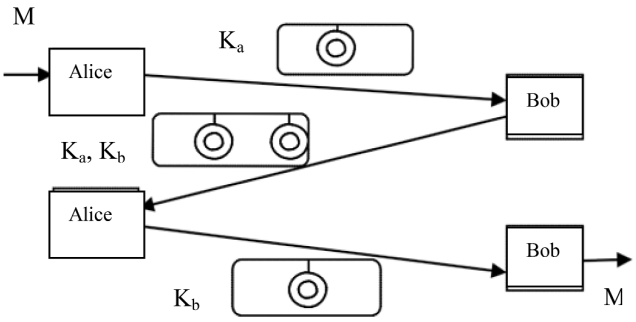

Figure 2. Sending secret in locked box using separate locks by Alice (K_a) and Bob (K_b); locked box shown as 

Although the locked box is the most popular foundational unit of traditional secure systems, it is not the only one. Another basic unit, with lesser popularity in formal arrangements but equally great popularity in informal systems, is that of the piggy-bank (Figure 3) in which coins or money can be easily inserted but not withdrawn without access to the key with which it has been locked.

> *Jehoiada the priest took a chest, and bored a hole in the lid of it, and set it beside the altar, on the right side as one cometh into the house of the LORD: and the priests that kept the door put therein all the money that was brought into the house of the LORD.* -- 2 Kings 12.9

We propose that use of such a locked box with a receptacle for insertion of money (or secrets) can be the model for cryptographic systems. Although used for collecting money at a public location, the box was sometimes moved to another location for counting the money and bills. In our case, instead of the use of a lock, we will use the cryptographic primitives of exponentiation modulo a prime or a composite number or other mathematical one-way functions. This will be explained

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by the development of protocols which in essence implement the piggy bank idea.

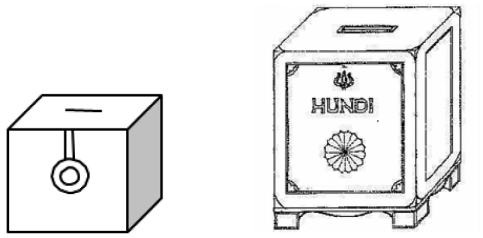

Figure 3. (a) A piggy bank; (b) A temple money box.

II. THE PIGGY BANK TROPE

Bob sends an empty locked piggy bank to Alice. When she receives it, Alice deposits the secret (money, bills, and jewels) into the box together with the decryption key of a coded letter. In addition, she prepares a letter to be sent separately. The piggy bank and the letter are sent back to Bob.

The letter is required to authenticate the contents of the locked piggy bank box. It cannot be in plaintext because the content list itself is a secret. The letter is needed to establish the identity of the person who has sent the secret (that is Alice) and this may carry an additional secret.

Bob opens the box, obtains the secret, and also reads the coded letter which has further details of the secrets in it.

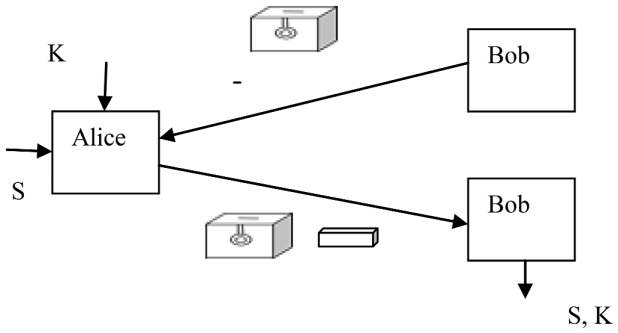

Figure 4. The piggy bank cryptographic trope; the secret letter is represented by 

The idea of sending two pieces of secret information in partitions was used earlier by the author in the different context of visual cryptography [4]. In the case where Bob's ability to read the "secret letter" is limited, he will be able to obtain only one of the two secrets.

The piggy bank trope can be implemented in many variations by making further assumptions about the system. Here we provide a few where standard primitives are employed.

Protocol 1

In this implementation of the piggy bank protocol for data, Bob obtains both the secrets K and S. The protocol consists of three steps of Figure 5:

Step 1. Bob starts with a random number R and the piggy bank transformation is represented by a one-way transformation $f(R) = R^e \bmod n$, where n is a composite number with factors known only to him; e is the publicly known encryption exponent. The number n needed for computations is provided by Bob to Alice.

Step 2. Bob sends f(R) to Alice who multiplies it with her first secret S. Alice sends $S(R)^e + K \bmod n$ to Bob in one communication and $f(S) = S^e \bmod n$ in another communication.

Step 3. Bob uses his secret inverse transformation to first recover S and having found it he can recover K.

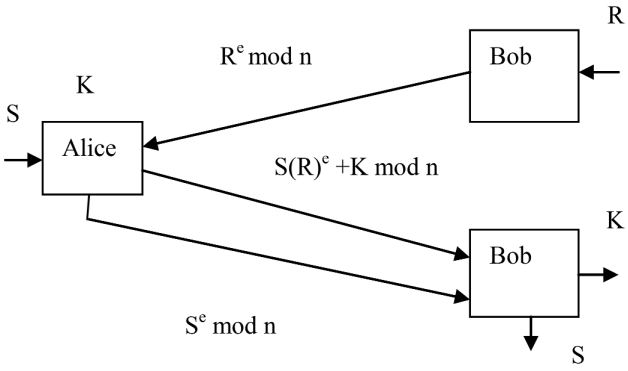

Figure 5. The piggy bank Protocol 1 for communications

EXAMPLE 1. Let n= 51 and the public encrypting exponent is e=3 (with the secret decrypting algorithm being 11 since $3\times11 = 1 \bmod \varphi(51)$). Bob chooses random R=13 and sends $13^3 \bmod 51 = 4$ to Alice.

Alice's random secrets are S=5 and K=29. Alice computes $4\times5+29= 49$ and sends it and also $5^3 \bmod 51 = 23$ to Bob.

Bob uses his secret decryption exponent to recover S: $23^{11} \bmod 51 = 5$. Thus $5\times4+K =49$, from which he recovers K.

Variations on Protocol 1:

Many variations to Protocol 1 can be devised. These variations require correspondingly appropriate actions by Bob.

1. Take R=1. This means that Alice sends S+K mod n and S^e mod n. This variation is a special case of the protocol of Figure 5.
2. Alice sends R^{eS} mod n and S^e mod n to Bob. This is a twist on the protocol as described.
3. Bob sends R to Alice who, in turn, sends S^eR+K mod n and S^e mod n to Bob. In this variation, the value of e is 1, which requires a slightly different transformation by Alice
4. Bob sends R to Alice who, in turn, sends SR+K mod n and K^e mod n to Bob. Here also the value of e is 1.

Protocol 2
In this implementation Bob obtains only one of the two secrets. The two parties also obtain an additional shared random number. The protocol consists of the following steps:

Step 1. Bob starts with a random number R and the piggy bank transformation is represented by a one-way transformation f. The transformation could be exponentiation of a publicly announced generator g of the elements of the multiplicative group modulo p, which is a prime.

Step 2. Bob sends f(R) to Alice who conjoins it with the secret S that she wishes to send to Bob and then performs the transformation f. It is assumed that f(S*f(R)) = f(SR), so as to ensure that the operations performed by Bob and Alice are similar. Now Alice sends f(S*f(R))+K to Bob which is equivalent to f(SR)+K as well as f(S) separately.

Step 3. Bob performs f(R*f(S)) which is equivalent to f(SR) since he knows the value of R. Now he subtracts it from f(SR)+K and, thereby, obtains K.

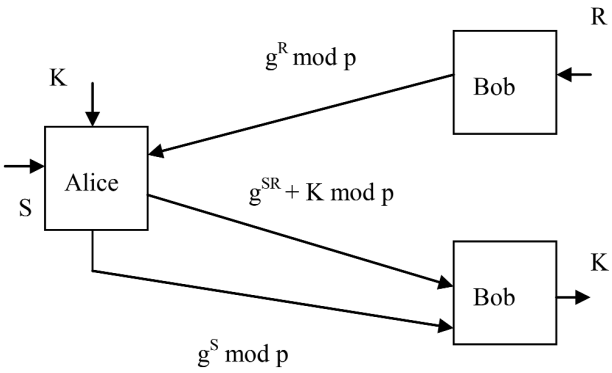

Figure 6. The piggy bank Protocol 2 for communications; f(Sf(R))=f(SR)

In a variant of this protocol, Alice sends K×f(Sf(R)) + K and f(S) to Bob, although this does not provide any special advantage.

An implementation of the protocol is given in Figure 6.

EXAMPLE 2. Let $f(x)=g^x$ mod p, where p is prime. Let p=37, g=2, and R=11. Therefore, Bob sends 2^{11} mod 37 = 13.

Let Alice's secrets be S=3 and K=10. Alice generates 13^3 mod 37 = 14 and sends 14 + K that equals 24 and also 2^S mod 37= 8.

Bob computes $(2^S)^{11}$ mod 37 and obtains 14. Subtracting this from 24, he obtains the secret K to be equal to 10.

Alice and Bob also come to share the random number g^{SR} mod p that could be used for some other cryptographic purpose.

Like protocol 1, protocol 2 can be implemented in other variations including one of the secrets is conjoined with the other encrypted terms in a multiplicative way (rather than the additive way shown here). It may also be generalized. The secret letter may be replaced by a hashing digest in certain situations (as in the application to quantum cryptography described below).

III. HASHING DIGESTS IN QUANTUM CRYPTOGRAPHY

The piggy bank trope may be applied to quantum cryptography [5]-[9] although this cannot be done in quite the same way as in the protocols above. Specifically, we can use the second "letter" communication from Alice to Bob to send a hashing digest of the key to determine if the bits have been correctly received.

Consider the communications [10]-[12] and signal-to-noise (SNR) perspectives on cryptography [13] where one must remember that quantum information processing suffers from unique challenges [14]. The BB84 protocol requires that single photons be sent by Alice to Bob [15], but the ability to receive single photons means that the SNR ratio for the receiver is infinite and the channel is fully protected. With such transmission requirements, there may very well be no need to use encryption!

In BB84 we could do away with complicated error correction, like "cascade", to counter the eavesdropper if the resources for computing commonly available on the network are harnessed to send side information.

In cascade, the sifted key bits are divided into blocks and then both parties announce the parity of each of these blocks on a public channel. If Alice's parity for a block differs from Bob's, it is clear that there are an odd number of errors in that block. The search for these errors is done recursively, by dividing the block into smaller ones, until only an even number is contained in that block. When the blocks have been processed, the bits are shuffled and the procedure repeated. This is done a number of times, so that the probability that the remaining key contains an error is very low.

Instead of the cascade procedure, a cryptographically strong hash digest of the raw key can be sent to Bob to ascertain if the eavesdropper has siphoned off any photons or if noise has led to any errors. This digest may be sent separately to the destination quite like the "coded letter" of Figure 4. If the digest generated by Bob doesn't match the one he has received from Alice, he asks for a retransmission of the bits.

In the use of hashing as a resource, the hash digest may be shared amongst the users on a side-channel since it is assumed that bandwidth is not limited. The BB84 protocol assumes that the data is being transmitted by single objects (photons) for if more than one photon is transmitted for each bit, the eavesdropper can siphon off the superfluous bit to obtain partial information about the key being transmitted. Of course, not all quantum cryptography systems use single photons as evidenced by the three-stage protocol using random rotations [2]. But even here the number of photons in each communication must be restricted so that the eavesdropper does not have information to determine the polarizations in each of the three links.

It is true that the use of the hashing digest will not prevent the eavesdropper from disrupting the communication.

IV. CONCLUSION

This paper has shown how the trope of the piggy bank can have cryptographic applications in communications and key-distribution systems. Using cryptographic primitives such as exponentiation modulo a prime or a composite number as one way functions, we have provided examples of basic use in classical and quantum cryptography. Further variations on the protocols provided in this paper may be easily developed.

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Investigation of System of Criteria within Selection Processes for ERP Systems
A Middle-European Perspective

Bálint Molnár, Gyula Szabó and András Benczúr

Abstract— **The application and introduction of ERP systems have become a central issue for management and operation of enterprises. The competition on market enforces the improvement and optimization of business processes at enterprises to increase their efficiency, effectiveness, and to manage better the resources outside of the company. The primary task of ERP systems is to achieve the before-mentioned objectives. For this reason the selection of a particular ERP system has a decisive effect on the future operation and profitability of the enterprise, i.e. the selection phase is highly relevant step within the introduction and implementation stage of an ERP system. The issues that are worth investigating are the criteria applied at the decision. The qualitative correlation between the size of enterprises, market position, etc. and the applied selection criteria for ERP systems could be analyzed as to whether which criteria are made use of at multinational enterprises or at SMEs. Our research is grounded in a literature review and case studies of everyday practice related to introduction, implementation and roll-out of ERP systems and it tries to provide answers for the above raised questions..**

Index Terms—**Business, Enterprise Resource Planning, Information Systems, Information architecture, Information management, Information processing.**

I. INTRODUCTION

SURVEYS and practical experiences have shown that all areas of enterprise operation have been affected by cost savings including the IT related fields, the main objectives are modified to increasing the economic efficiency instead of earlier ones. The economic crisis has resulted generally in dramatic impact on IT budgets at enterprises. The GDP of World has increased only by 1.8%, within the European Union has decreased in average by 0.2% in 2010. In spite of efforts for cost-efficiency, the enterprises invested into product developments (48% in the survey) beside IT (48%). However, the IT budget decreased by 6% at enterprises involved in the survey in 2009. A slight budget increase is projected in 2010 from 2009's historic budget cuts; but the increase still left the IT function at enterprises with fewer resources in 2010 than they had in 2008. In 2011 a moderate increase for spending are anticipated [43].

In spite of the enduring economic and financial crisis, the introduction and adoption of ERP systems continues. We have investigated the trends in a small EU member country (Hungary) empirically and by publications related to business management and economics. There are clear tendencies that even the small and medium enterprises (SME) that had data processing systems which had been previously developed individually or tailored to the specific requirements started projects to buy ready-made or commercially available Off-The-Shelf (*COTS*) products on the market. The reaction to enforcement for modernization by technology and business processes is to procure, customize and integrate easily accessible program packages on the market. The main reason is that the previously developed, legacy systems cannot comply with the recent requirements related to information processing, namely cost-efficiency, staffing level and other labor conditions.

The program packages that support the operation of enterprises comprehensively have been denominated as ERP (Enterprise Resource Planning) systems; however there is serious criticism whether the technical terminology is consistent with real content and with the notion of "planning". Nevertheless, the ERP systems achieve an enterprise-wide integration that affect the whole enterprise, the group of companies, moreover the member companies of supply chains. The vendors involved in the eco-system of the given company enhance the particular implementation of ERP system with extra functional content. The ERP system should cover requirements at companies in various industrial sectors having different manufacturing procedures – as series production, custom-made individual products, mixed assembling processes, integration to CAD systems, process engineering, especially in chemical industry where the continuous controlling of chemical processes is needed to monitor the basic materials how they are mixed for production of plastics [14]. There are ERP systems that are dedicated to large and medium sized enterprises, to particular sectors as commerce or to companies having business functions overarching from manufacturing to sales and delivery [11]. Packages devoted to SMEs where the owner generally at the same time the managing director and the companies are flexible, resilient,

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adaptive ones with low staffing level are proliferating as well.

There are individually developed systems, e. g invoicing programs that are linked not only one industrial sector but could be applied in several sectors, however they cannot be considered as a standard solution. We conclude that there are **individually developed** and **standard systems** within the industrial sector specific solutions as so much as among the general purpose systems created for supporting enterprise governance can be found standard and specifically developed ones.

In this paper, an **ERP system** is understood as an enterprise-wide, comprehensive information system involving all information processing activities that covers the human resource, production, commercial, planning, inventory, material planning, management control and monitoring business processes by placing them into a unified framework.

The *ERP systems* are composed of several functional services that are implemented as modules. Considering *ERP systems*, the concept of modules and their mapping to business services and processes are diverse, however their fundamental property is incorporated in the fact that they are grounded in one, unified database, moreover they provide the opportunity for step-by step introduction, implementation and roll-out.

The fundamental benefits of ERP systems do not in fact come from their inherent "planning" capabilities but rather from their abilities to process transactions efficiently and to provide organized record keeping structures for such transactions. Planning and decision support applications represent optional additions to the basic transaction processing, query and report capabilities included with a typical system. ERP systems represent corporate infrastructures, much in the same way that physical highway systems or telecommunication infrastructure of a country do.

The selection of an adequate ERP system is not an easy task for any future, potential user as the experience shows that any information processing system – even the outstanding ones – is worth for the user inasmuch as the user organization can enable a part or the whole of the system to utilize or exploit the functionally provided by automated solution. The implementation is a part of a long preparation that is independent from the fact as whether to the selected solution which environment will be operated in. The success or failure of implementation ERP systems is widely discussed in several publications. In next chapters, we analyze the phases of implementation process and providing some answers for the raised issues. The qualitative correlation between the size of enterprises, market position, etc. and the applied selection criteria for ERP systems could be analyzed as to whether which criteria are made use of at multinational enterprises or at SMEs.

We have grounded our investigation in theses that were created on ERP at a Hungarian College as students' research project. There was an empirical research on architectural approaches of subsidiaries belonging to international companies and operating in Hungary [12]. The research was carried out by a consortium of Hungarian Universities and Colleges. However, the previous research focused on the enterprise and information architecture, the experiences on ERP introduction and selection process have been built in this recent research. Beside companies situated in Hungary, the investigation covered practice of ERP introduction at several German companies either based on publications or in-depth interviews with managers responsible for ERP systems.

There was a comprehensive literature review related to ERP introduction and implementation that we will discuss in detail.

II. LITERATURE REVIEW

There are several, concurrent definition and circumscription for ERP, we have tried to collect some of them to get a touch and feelings about the ERP systems:

1. "A process by which a company (often a manufacturer) manages and integrates the important parts of its business. An ERP management information system integrates areas such as planning, purchasing, inventory, sales, marketing, finance, human resources, etc. ERP is most frequently used in the context of software. As the methodology has become more popular, large software applications have been developed to help companies implement ERP in their organization. Think of ERP as the glue that binds the different computer systems for a large organization. Typically each department would have their own system optimized for that division's particular tasks. With ERP, each department still has their own system, but they can communicate and share information easier with the rest of the company" [23].
2. Latest phase in the development of computerized systems for managing organizational resources. ERP is intended to integrate enterprise-wide information systems. ERP connects all organizational operations (personnel, the financial accounting system, production, marketing, distribution, etc.) and also connects the organization with its suppliers and customers [41].
3. A collection of applications that can be used to manage the whole business. ERP Systems integrate sales, manufacturing, human resources, logistics, accounting, and other enterprise functions. ERP allows all functions to share a common database and business analysis tools [50].
4. Enterprise resource planning (ERP) is an integrated computer-based system used to manage internal and external resources including tangible assets, financial resources, materials, and human resources. It is a software architecture whose purpose is to facilitate the flow of information between all business functions inside the boundaries of the organization and manage the connections to outside stakeholders. Built on a centralized database and normally utilizing a common computing platform, ERP systems consolidate all business operations into a uniform and enterprise wide system environment. [5].
5. An industry term for the broad set of activities supported by multi-module application software that help a manufacturer or other business manage the important

parts of its business, including product planning, parts purchasing, maintaining inventories, interacting with suppliers, providing customer service, and tracking orders. ERP can also include application modules for the finance and human resources aspects of a business. [21][21].

6. A business management system that integrates all facets of the business, including planning, manufacturing, sales, and marketing. As the ERP methodology has become more popular, software applications have emerged to help business managers implement ERP.
7. An ERP system is recently considered as a comprehensive, integrated application system, that unifies in itself functional services as processes for administration (order processing, accounting, inventory, customer credit/debit handling, etc.) , management (planning, monitoring, controlling, governing etc.), and disposal (shipping, purchase ordering, job shop scheduling, production control, etc.) [26].
8. The essence of ERP is "integrating the resource of the entire 'enterprise' from an information standpoint."[24]. The essences of ERP are information sharing (which is the same as a common central database) and process integration (the unique character of ERP systems).

ERP selection is an important decision making problem of organizations and influences directly the performance. The ERP selection process is tedious and time consuming as it has to deal with the complexity of business environment, and in project management sense it should solve problems of resource shortages. There are a lot of ERP alternatives in market [48]. The selection of best suitable ERP system provides positive results at enterprises like increasing productivity, timely delivery, reduction of setup time, reduction of purchasing cost. The failure in selection of ERP system firstly leads to the failure of ERP introduction or adaptation project or secondly to degradation of company performance [27]. It is a fact that software programs are costly and their adaptation takes too much time so that the cost of wrong selection is high.

Several research studies have been conducted to identify relevant factors having impact on success of implementation and introduction at ERP systems. The major part of studies have chosen the case study paradigm, i.e. many of them focused on single case study of ''how we implemented ERP systems in our company'' ([2], [6], [31], [51]). Furthermore, several studies that have measured ERP implementation success used only one or two factors of ERP implementation success ([2], [3], [30], [47], [44], [45]).

The literature contains several viewpoints concerning what variables are required for implementation success or responsible for failure. The literature research shows that problems with the implementation of ERP systems emerge for a number of reasons.

We can summarize briefly the reasons as follows:

- Generally there is a need for business process change or re-engineering for fitting together the business processes and information processes of an ERP system. Leaving out the required business process alignment could lead later operational problems.
- Lack of commitment from top management, deficiency in data accuracy, and short of user involvement can attribute to system implementation failures appearing typically during the operation phase.
- Education and training to make use of ERP system are frequently under estimated and are given less time due to schedule pressures.
- The synergy demanded by cross-functional business processes are not understood properly.

The above mentioned issues may have consequences in case they are not handled within the project correctly.

An ERP system is a socio-technology system so that finding an exact definition of measurement for implementation success is hard task. There are competing measurement approaches and concepts coming from research literature and practice. Some factors that can be encountered in the literature:

- User satisfaction ([1], [2], [3], [31], [51]).
- Intended business performance improvements ([1],[20], [30]).
- On time ([1],[20], [30]).
- Within budget ([1],[20], [30]).
- System acceptance and usage ([2], [3], [51]).
- Predetermined corporate goals ([1], [47], [51]).

A case study examines a phenomenon in its natural environment, applying multiple methods of data collection to gather information from one or a few entities (people, groups, or organizations). By its approach, case study paradigm as a research tool is well suited to the study of Information System (IS) implementation, especially when contextual environment is important and the phenomenon is temporary. The researcher has no control over the surroundings changing in time so that the research is typically qualitative investigation and exploratory to discover the answers for questions as the ''how'' and ''why''. It is suggested to utilize multiple case studies to enhance the methodological exactitude of study through ''strengthening the precision, the validity and stability of the findings'' [34]. The case studies paradigm provide a sound basis for scientific generalization if it is correctly used.

III. PHASES OF ERP INTRODUCTION

The reason why a decision may have been made to replace an operational system by an ERP solution can be concluded from several basic causes. One of the origins for such a decision is that the enterprise would like to save or strengthen its market position through acquisitions or internal growth. The IT/IS system can be adjusted to theses changes flexibly if there is a "quantum leap" in IS service quality by introducing an ERP system considered as a "best practice" in the industry sector. The other important factor is the competition on the market. The price competition enforces the companies to optimize, to make transparent of their manufacturing, procurement processes, furthermore to monitor their

performance and at the same time to increase the resource utilization of business processes. Beside the market competition there are other compelling sources to optimize and to increase performance in enterprise governance and information processing. These factors pushes towards to improve efficiency and effectiveness of enterprises. The major task of ERP systems is to provide a solution for the before-mentioned issues.

The samples in practice demonstrates that the introduction and application of ERP is a longstanding process. The selection of a proper solution is a several year project that can be divided up into stages however it takes time but the reward could be competitive advantage and efficient operation at enterprises. Perceiving the situation the vendors offer approaches to shorten the introductory time and to save costs. The required activities are planned and monitored till the introduction and operation by vendors so that they ensuring a successful project execution [14].

There is a seven phase model for ERP introduction: proposal for changeover, analysis, conceptual plan, short listing the potential solutions, selection process, decision for the designated one, and project closure [52]. In this study we define five stages taken into account the practical experiences: decision on changeover, selection of ERP solution, training, evaluation.

A. Modernization of operational system

The experience shows that protecting the market position, the growth of enterprises is accompanied by the demand for higher data and information processing volume. The companies frequently encounter a decision situation how they can modernize existing data processing system. There are three different ways: *development*, *package procurement* and *renting or leasing* the ERP services.

At the beginning it is difficult to decide whether a program package as COTS (Commercial off-the-shelf) should be procured or a supplier should be found to develop a customized solution who can adapt its basic system to our requirement. The decision is hard as the package solution cannot cover all business processes at the enterprise. A developed system may comply with requirements and it can be tailor made for specific business processes; however it requires more resources[4].

Before the decision between the package solution and development an analysis can be carried out on potential solutions then a management decision is made. During the analysis the benefits and disadvantages of the package solution are assessed.

Benefits:

- Short introduction time;
- Lower costs than development;
- The package solution incorporates long term experiences in the sense of integration:
  - Contains fewer deficiencies as it has got through serious defects elimination;
  - Provides potential advanced governance, control and management solutions to be realized;
  - It integrates various and different business areas and functions;
  - The external relationship as the supply-chain management, customer relationship has been integrated;
  - New information and software technology is instituted;
  - The mounting data processing requirement is handled by architecture to be scaled.

The disadvantages of a package solution:

- There is generally a discrepancy between information services of the package and the business process of the organization;
- To integrate the new requirements into a package needs more resources and costs as development from scratch;
- Hardware infrastructure enhancement is necessary procuring new software system;
- The utilization of staff at the IT function in the enterprise decreases and the skill and knowledge of staff does not develop.
- The dependency on the vendor grows; the requirements for change can be satisfied only by the assistance of the vendor ([10], [42]).

The third opportunity is renting or paying a fee for all or some services of an ERP system. At small and micro enterprises, frequently there is a lack of knowledge and skill of business management, e.g. on the field of calculation for a quotation, or material management. The current ERP systems contain proper information system processes for managing and controlling micro enterprises as well. The financial resources at small and micro enterprises had not made a real option to procure an ERP system previously and to employ staff having skill in IT operation.

However most recently, the **ASP (Application Service Providing)** is an appropriate, cost-effective solution for micro and small enterprises. The services can be accessed through the **Cloud Computing** too.

In the life of many companies arrive the moment that the decision on modernization of the enterprise management system cannot be postponed, i.e. the management should start a project for selection a proper ERP solution and initiate the decision making process.

B. Decision making on the introduction of an ERP solution

The question emerges whether what the factors are that lead companies to consider replacing the operational legacy system fully or partially with a new information system.

To find answer for the question we have investigated cases covering a wide spectrum and we have collected and highlighted justification from the projects executed to introduce ERP like systems.

A Hungarian Ltd. decided to adopt an ERP (ProFinance™, http://www.profinance.ch/deutsch/index.asp) system, their justification contained three items having grounds in the underdeveloped, legacy information processing system:

- The rapidly developing enterprise owned old, legacy information processing system that did not cover all business processes. For this reason, the introduction and implementation of a more modern enterprise management system became the must.
- In the region, the other, concurrent companies have adopted and will have implemented various management systems gaining competitive advantage.
- There is intention to develop and to extend the retail branch of the enterprise. The new information system should have a steady and reliable on-line connection between the retail shops and the wholesale units.

The advancement in IT that has led to decreasing in price of hardware has resulted in acceleration of information system development to replace the legacy systems.

A company (Borstlap b.v.) from Netherland had an AS/400 based system named TOTICS and had operated for 20 years. At the beginning, the system satisfied perfectly the customer requirement, moreover the continuous development for enhancement and improvement sustained the daily operation. However, the system slowly became obsolete in spite of all efforts. There was no support for accounting, finance, human resource management and other important business areas of the company. The system lagged behind supporting management of modern systems. The information to supply management decision was difficult to retrieve, sometimes impossible. The question "Whether does the company need a new information system and if the answer yes then why?" has been responded:

- The new system is pre-condition to realize the business strategy plan;
- The new IS provides better reliability, higher service level for customers;
- Within the business group is to increase efficiency and to make more transparent the business process;
- The system should support the business planning and consequently the cost-efficiency and serving the clients;
- The new IS creates the opportunity for an integrated system[46].

The subsidiary of a multinational oil company in Hungary used to employ JDE (J.D. Edwards) ERP system. The company has roughly 100 subsidiaries world-wide and they had applied a wide variety of ERP systems. The company decided to eliminate the heterogeneity of systems. The enterprises wanted one integrated solution. Considering the opportunities, the top management of multinational company made the decision for a project called Global SAP, GSAP project [25]. The Dutch company settled to introduce SAP R/3 as well.

In one of our empirical research, we have met the following approach ([35],[12]): some business administration functions are centralized at some regional headquarters as e.g. invoice processing and payment. The SAP FI module is procured and customized to be dedicated to this task. The customization primarily meant specific parameters that reflect the country specific legal environment. This research pinpointed to the fact that the country-specific and country-wide solutions used previously have been replaced by ERP modules as finance, sales and delivery, customer and supplier management. Consequently, a business function is covered totally by a single ERP module introduced during the changeover.

In the above mentioned cases, the selection phase has been left out. The top management at both companies has made a strategic decision choosing an ERP system that is considered as best practice.

Within the globalised business life, both example (the Dutch and multinational oil company) highlight the causes that has led to the decision for changeover and application of an integrated ERP.

C. Causes for Changeover

As the before mentioned cases demonstrate, the base for a changeover to an ERP system consists of:

- the requirement for information processing volume caused by the growth of business, acquiring larger market share or the intention of it;
- necessity for modernization of legacy systems;
- the requirement for company-wide integration, unification and creating uniformity in information processing.

However, there are issues to be considered before decision on a changeover:

- Whether are consultants needed although the system will be operated by the staff at the enterprise?
- Whether the costs, the whole project budget can be planned in the selection phase? Some issues:
  - Fix cost at one-time investment, and variable cost at operation time;
  - Infrastructure investment and procurement;
  - Business efficiency and effectiveness of the new IT/IS solution;
  - Can be higher income for the enterprise anticipated?
  - Training and education for the employees and their costs including to maintain the skill level.
  - Would the inventory management be improved?
  - Which are the business areas where cost savings can be achieved? Efficiency of production could decrease the costs of salaries and wages?
  - Whether should a save deposit be established for financing the unexpected cost growth after ERP implementation?

D. Objectives of ERP selection and practical approaches

The difficulties in selection of ERP system did not originate from the fact that too few ERP system is available on market, in spite of it there are the multitude of ERP system. There are hundred vendors beside the major players in Germany [15].

The primary vendor selection could be based on the market position within the specific ERP sector[33]. There are four factors that can be combined variably to represent the market position within competition in a Cartesian chart, namely the competitive advantage, financial soundness, technical knowledge and skill, the stability of business environment.

The ERP system vendors can be shown in such a chart.

The investigation of potential ERP solution should take into account business and financial consideration beside the information technology viewpoints (e.g. software and programming environment, information system function etc.). A Hungarian Ltd. (TMF Magyarország Kft) had as selection goals for ERP:

- the system supplier should be a domestic vendor, the vendor should commit itself for satisfying the users' request for change;
- user friendliness, easy handling of user interface and ability for customization;
- capability for integration and interoperation with other systems;
- The IT stability of IS should be high [9].

E. Business Case

One of the major objectives during ERP selection is to mitigate the risks inherent in the selection process. In literature, there are lots of methods and models that have been widely discussed; two of them is outlined below.

When management considers several conflicting goals to be achieved, multi-criteria decision making (MCDM) models enable effective results in the ERP selection process. Subjective decision-making processes related to conflicting business problems with trade-off relationships may produce sub-optimal results. Appropriate ERP strategies must be established on a compromise-based and objective decision-making process among diverse stakeholders ([7], [38]).

Analytic hierarchy process (AHP) is a generally used method for arranging goals, objectives in a hierarchical order. The basic aim of method is to support the decision making in a systematical manner using mathematical and computational procedures.

The basic problems with both approaches is that the mathematical theory in background should be understood by top management and other stakeholders participating in the decision making process. One of the potential solution for that problem is to provide a simplified model for management that clearly defines the alternatives to make the selection easy [39].

Both MCDM and AHP are discussed in literature, there are some case studies where the application of methods is demonstrated ([49], [19]). In our research, we have not encountered any sample where either MCDM or AHP approach has been used. The complexity of transformation from a system of multiple-criteria on quality to numbers and measures may be one of the reasons.

Besides the business and technical criteria and risks there are financial ones too. The financial perspective is based on cost savings and quantifiable implementation benefits. Evaluation methods include Net-Present-Value, Cost–Benefit Analysis, Payback, Return on Investment, etc. To assess the financial parameters one of the analysis models is the ROI (Return on Investment) that can be applied.

There is an elaborated method that consists of several hundred questions. The inquiries address the efficiency of information processing taking into account the particularities of various industry sectors and size of enterprises. However, the extensive questionnaire does not solve the problem deriving from lack of information at stakeholders. There is a dearth of reliable information on the following subjects [18]:

- knowledge of the actual functions within the ERP system;
- the applied software and –generally – information technology;
- the market position, the economic capability, viability of the potential vendor;
- the comprehensive view of the alternative, competing solutions existing on market;
- the potential improvement of information processing;
- the comparative analysis of references for alternative solutions and their implemented instances.

However, there are controversies on whether which financial analysis approach fits bet to a successful ERP selection process, there are positive examples that demonstrates that ROI is a good compromise for assessing the financial risks of an ERP adaption process and other socio-technical viewpoints[28].

TCO (Total Cost of Ownership) has been used by some cases as well. The comparison of the potential alternatives as procuring, renting, leasing or paying per usage for services through Cloud Computing can be carried out by TCO approaches. A well founded TCO model provides the opportunity for controlling the costs known in advance in the future and the flexible reaction to the changing business environment by enterprises. At Hungarian Ltd. the TCO model was employed to analyze the costs for introduction and operation. The main components were as follows:

- capital expenditure (46 %, hardware, software, network);
- system administration (12% upgrade, update, maintenance);
- technical support (16%, hardware maintenance, supervising, virus protection, other technical services);
- end-user supports (26%, training and education).

F. Soft Criteria for Selection

Besides the service quality and financial criteria, there are lots of other objectives that should be taken into account during the selection process. The compliance to the requirements of the company is one of the most important criteria. To clarify and to define accurately the compliance criteria, a business process modeling should be carried out to discover and to map the whole business process that will be involved in the ERP introduction. To explore the discrepancies between the existing processes and the processes of potential ERP systems, a *gap analysis* should be performed. The questions are: which business processes can be automated by the ERP system, which business processes should be adjusted to the ERP system processes, and which ERP system process may be slightly modified to the current or aligned business processes.

The new ERP system may fulfill the recent requirements; however the ERP system should be prepared for future demands [29]. The stability of information systems means the adaptability to changes of technology, business processes and business environment so that anticipated feature of ERP system is certain degree stability.

The issue of stability has got specific interpretation in the case of ERP systems. ERP systems are software packages that can be tailored to the specific requirement in a certain degree. ERP systems generally contain many functions. During the gap analysis, the functions and their modules are chosen that fits to the decision regarding that what business process will have been automated. The experiences shows that if the set of functions is minimized for several reasons – financial, compliance, project timing, resources etc. – then later on, the enhancement and evolutionary development to react to the changing environment may cause extra costs and other operational difficulties in spite of the maximization of collection of functions [15]. The augmentation of an implemented ERP system with new functionalities leads to higher expenditure. It seems a better solution considering costs and benefits to buy the potentially applicable functions and then if necessary the required function is made operational.

The flexibility of ERP systems is a success criterion within the corporate and SME world [14]. In this context, the *flexibility* is an overarching concept that involves the simultaneous use of various languages carrying out even the same task, at the same time, furthermore adaptation to the changing business and market environment. Acquiring new markets or setting up factory in foreign countries may mean totally new logistics or supply chain system which the ERP system should be adjusted to. The multi-national enterprises operating on various markets in different countries have as basic interest that their information system should support both specific requirements at each single country and requirements at corporate level. The headquarters of multi-national corporations tend to centralize their management, control and governance systems to ensure an integrated and unified business administration. This tendency results in globalised ERP systems. The top management at the center of enterprises has various opportunities to find a satisfactory solution among the potential ERP systems ([12], [35]).The concrete implementation is situated in the centralization-decentralization continuum both horizontally and vertically regarding the Zachmann architecture to provide the support that is required the top management of enterprises.

Other uncertainty factor is the structure of business processes and organization and the capability for adjustment to the processes provided by an ERP system. A German company had outsourced the business processes for sales and distribution to several third parties. However, the company has acquired a firm that was specialized in sales and distribution so that the German enterprise has eliminated the outsourcing and incorporated business processes related to sales and distribution. On integrating the newly acquired subsidiary, a new ERP system dedicated to customer-supplier relationship has been introduced at the same time. The new system supports the business processes from quotation, through contracting and distribution to shipping. A serious and conflict generating task was the re-engineering the business processes related to the outsourced sales and distribution functions and adapting them to processes at the subsidiary. Finally, the project achieved their goals. The ERP system adaptation and transformation of business processes has as outcome a solid market position. The ERP system adaptation may have as a side-effect stronger market position, efficient internal business processes and a profound transformation of whole activities in the enterprise.

On selecting an EPR system to support globalised business activities, so-called country specific features should be taken into account. Such features include as follows:

- custom and excise handling;
- tax, revenue handling;
- commercial code;
- financial an cost accounting;
- banking, rules for bank accounts;
- local legal environment, jurisdiction.

The potential ERP system may or may not contain the above listed, country specific features. An enterprise operating on the globalised market should consider these particularities and make decision to make up for the lacking functionalities. The required customization needs extra implementation effort generally. Some examples for the difficulties that occurred [8]:

- Country specific, compulsory Chart of Account (Belgium);
- Accounting the transfer prices (Brazil);
- Handling and accounting the billing credit (Bulgaria);
- Country specific Payroll (Chile).

The described cases underpin the fact that during the selection process business–oriented criteria play important role besides financial considerations. Such factors are as follows: user friendliness, usability, interoperability and/or compatibility, common requirements for ERP systems, reputation of vendor and its products, capability of system for application in a globalised business eco-system overarching several, different countries.

G. Summary of Experiences

In this research we have investigated twelve Hungarian companies, sixteen subsidiaries of multi-national companies operating in Hungary at a previous research [12], and five companies in Germany [40].

The cases show that criteria on financial, business, technical and market position play role within the selection process of ERP system. The aspects are as usability, interoperability, compatibility, functionality of system and the reputation of the vendor and its products, and the applicability locally or globally.

- The criteria that are worth taking into account are as follows:
- current market position and long term sustainability and viability on market;
- the alignment and/or the capability for adjustment of the potential ERP system to the specific industrial

sector or business area, the references of successful implementation;
- financial and business parameters;
- the degree of dedication of rival enterprises to implementation and application of ERP solutions;
- interoperability, capability for integration to other legacy systems to be kept in operation;
- the applied technologies for data management, software and information processing;
- the support provided by the vendor at the introduction and operation of the system;
- The costs and options for maintenance, upgrade, update and adaptation to the changing legal environment;
- language versions, localization opportunities in the case of multi-national, global companies;
- existence of country specific solutions at some business areas (e.g. accounting);
- IT networking capability of ERP system to be adjusted to recent state of the decentralization-centralization demand.

The theoretically complex approaches grounded in mathematics for assessment are used rarely nevertheless the business or financial models for evaluating the benefits and costs can be met frequently. The financial models as 'Return on Investment', 'Net Present Value' etc. can be computed in spreadsheets. There are models prepared in spreadsheets or in text books that can be readily applied in spreadsheets. However, MCDM, AHP and ANP require modeling efforts and do not exist easily available tools for carrying out the mapping between the quality criteria and their mathematical representation. The intention to use fuzzy versions increases the complexities and difficulties to be dealt with. In a commercial environment, there is not enough knowledge to use the complex approaches even if third party consultants are involved.

H. Solutions and Recommendations

The case studies show by the experience that the ideal typical approach for ERP introduction and implementation as follows:

- A carefully elaborated project plan is required to schedule the activities, tasks for implementation of ERP system. The plan is accepted and monitored by the top management to support the team dedicated to the ERP system adaptation.
- The proposed stages for changeover:
  - PERT /CPM network for the whole project;
  - Formal project initiation including the staffing the project team, detailed planning the single tasks;
  - A selection process for ERP;
  - Customization of the selected ERP;
  - Designing and introducing data coding scheme, data conversion process;
  - Testing the ERP system;
  - Re-engineering the internal business processes of the enterprise ;
  - Training and education for user how to use the ERP system, and periodical re-training;
  - Formal launching the system for operation;

The occurring, new user requirements should be satisfied by development whereas it is needed to ensure the continuous maintenance, e.g. update and upgrade of software and hardware in order to keep the system up-to-date within changing internal and external business environment.

IV. FUTURE RESEARCH DIRECTIONS

The future research should deal with the changing IT environment, especially the proliferation of *Cloud Computing*, the Software as a Service (SaaS), the application as a service, namely the ERP system services. In this situation, it will be worth investigating how the notion of ASP (Application Service Provider) changes and what the particular features may have regarding the ERP services. Similarly important phenomenon is the concept of Web services and its promise the flexible configuration and re-configuration of information system services along with the business processes.

These rapidly changing IT / IS environment enforces to raise the same research questions on issues of selection, introduction, adoption, customization and operation of the ERP service.

We have investigated in multiple case studies criteria for selection of ERP systems. We have encountered various viewpoints out of customer organizations and financial and business models applied for evaluation. Another thread of investigation could be whether what computational intelligence and other computational models may be employed in the before-outlined changing environment that could flexible fit to the given situation and may provide useful information for the customer.

V. CONCLUSION

The multiple case studies and financial analysis models presented in this paper provide assistance for the decision making processes at enterprises where the changeover issue is reviewed.

The results of research can be summarized in a table as a conclusion (Table I): The results of research can be summarized in a table. The assessment of each single factor is founded on analyzing the in-depth interviews, case studies, scientific, technical, business publications and other reports, overall *40 companies* were involved in the research. We have analyzed the *frequency of occurrence* of each single selection criterion in case studies and their exercised impacts on the final success of ERP systems.

Factors' effects on ERP implementation	**Occurence in case studies**						
	weak positive impact	average positive impact	strong positive impact	Neutral	average negative impact	weak negative impact	strong negative impact
Top management support	8	5	6	6	2	3	3
Company-wide support	8	5	4	4	4	4	4
Business process reengineering	1	2	6	6	6	6	6
Effective project management	7	7	7	3	3	3	3
Organizational culture	1	2	4	4	9	6	7
Education and training	2	7	12	3	3	3	3
User involvement	1	2	6	6	6	6	6
User characteristics	2	3	7	3	3	7	8
ERP software suitability	8	8	12	2	1	1	1
Information quality	8	8	12	2	1	1	1
System quality	8	8	12	2	1	1	1
ERP vendor quality	2	8	12	7	1	2	1
Total :	56	65	100	48	40	43	44

TABLE I
FACTORS HAVING IMPACT ON ERP INTRODUCTION AND IMPLEMENTATION

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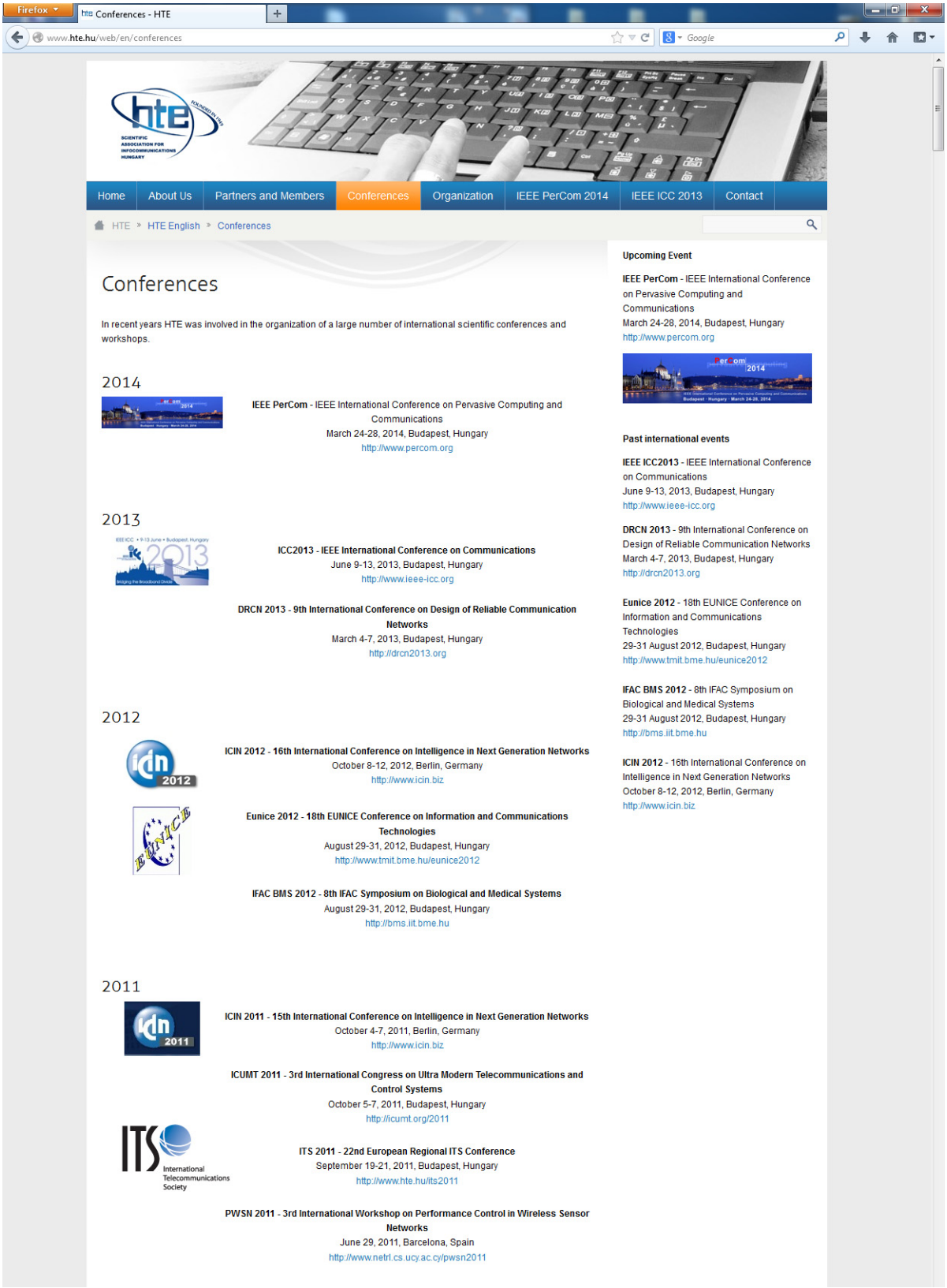

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ICIN 2010 - 4th International Conference on Intelligence in Next Generation Networks
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http://www.intellicis.eu

2009

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2008

ICIN 2008
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www.networks2008.org

2007

Mobilesummit 2007 - 16th IST Mobile and Wireless Communications Summit 2007
July 1-5, 2007, Budapest, Hungary

ICIN 2007
www.icin-conference.com

2006

ISD 2006 - International Conference on Information Systems Development
New Methods and Practices for the Networked Society
August 31 - September 2, 2006, Budapest, Hungary

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Prof. Erol Gelenbe, IEEE Fellow and Communications Society member, also a member of our Editorial Board, has recently received the prestigious "In Memoriam Dennis Gabor Award" for outstanding research with important impact in innovation.

The "In Memoriam Dennis Gabor" Award is awarded by the NOVOFER Foundation of the Hungarian Academy of Sciences for outstanding scientific achievements with practical applications. It is named after Dennis Gabor, the inventor of holography, the 1971 Nobel Prize Winner in Physics. The award ceremony was held on 19 December 2013 in the building of the Hungarian Parliament.

Professor Gelenbe's practical inventions include the design of the first random access fibre-optics local area network, a patented admission control technique for ATM networks, a neural network based anomaly detector for brain magnetic resonance scans, and the "cognitive packet network" routing protocol to offer quality of service to users. He is known for contributing fundamental results on stability and control of random access communications, for inventing G-Networks an important generalisation of queuing networks, and the random neural network model.

Also Fellow of ACM, he won the 2008 ACM SIGMETRICS Life-Time Achievement Award for being "the single individual who over a span of thirty years has made the greatest overall contribution" to computer and communication system performance. He was elected to the French National Academy of Engineering (2007) and to the Hungarian (2010) and Turkish (2007) Science Academies and he is also a Foreign Member of the Science Academy of Poland. From 1984 to 1986 he served as the Science and Technology Advisor to the French Secretary of State for Universities. He founded the ISCIS (International Symposium on Computer and Information Sciences) series of conferences that since 1986 are held annually to bring together Turkish computer engineers and scientists with their international counterparts.

Erol Gelenbe (center), Winner of the Dennis Gabor Award with József Pálinkás (left), President of the Hungarian Academy of Sciences and József Gyulai (right), Chairman of the selection committee

Let us quote Professor Gelenbe's interesting speech at the awarding ceremony.

"Gabor Denes was indeed a giant, for his scientific contributions to physics that won him the Nobel Prize, for his great inventions, and his commitment to Europe and to his home country. He could have moved to America at several stages of his career, but chose to remain in Europe, and he contributed actively to the European idea.

Like him, many Hungarians have shaped Europe and the world through contributions to the arts, and to science and technology. Hungarians forged the great cannon for the siege of Constantinople in 1453. Hungarians introduced the printing press to Istanbul. Bartok wrote about the music of Anatolia and the Balkans. In the 20th century, the Hungarians Szilard and Teller contributed greatly to western security, and Wigner shaped our understanding of the universe.

I was born in Istanbul, but my scientific links with Budapest and Debrecen were developed while I worked in France, of which I am an active citizen. These Hungarian-Turkish-French links are interesting. The Baron Francois de Tott, born in Chamigny, France in 1733, worked in Turkey from 1755, and died in Austro-Hungary. Descended from Hungarians who had emigrated to the Ottoman empire and then moved to France with Count Miklós Bercsényi, he founded with my ancestor the Turkish mathematician Gelenbevi Ismail, the first Ottoman engineering academy. He had a role in Turkey similar to another French engineer, the Count (Comte) de Bonneval. My great-grandfather was Magyar Ibrahim Pasha, a naval doctor, and my paternal uncle, then a student, died in this city after the First World War.

In my own field, without John von Neumann, George Pólya, Paul Erdős and Rudolph Kalman, can we imagine the revolution in computation and automation? Today without Béla Bollobás and Albert Barabási can we understand the Internet?

As I recall our debts to Hungary, and the genii of Hungary in science and the arts, I thank you and stand humbled to receive the "in memoriam Dennis Gabor award", in this country that has so much impacted science and innovation."

Guidelines for our Authors

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Original manuscripts and final versions of papers should be submitted in IEEE format according to the formatting instructions available on
http://www.ieee.org/publications_standards/publications/authors/authors_journals.html#sect2,
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The length of papers in the aforementioned format should be 6-8 journal pages.
Wherever appropriate, include 1-2 figures or tables per journal page.

Paper structure

Papers should follow the standard structure, consisting of *Introduction* (the part of paper numbered by "1"), and *Conclusion* (the last numbered part) and several *Sections* in between.
The Introduction should introduce the topic, tell why the subject of the paper is important, summarize the state of the art with references to existing works and underline the main innovative results of the paper. The Introduction should conclude with outlining the structure of the paper.

Accompanying parts

Papers should be accompanied by an *Abstract* and a few *index terms (Keywords)*. For the final version of accepted papers, please send the *short cvs* and *photos* of the authors as well.

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References

References should be listed at the end of the paper in the IEEE format, see below:

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b) Title of article in quotation marks
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d) Volume, number, and, if available, part
e) First and last pages of article
f) Date of issue

[11] Boggs, S.A. and Fujimoto, N., "Techniques and instrumentation for measurement of transients in gas-insulated switchgear," IEEE Transactions on Electrical Installation, vol. ET-19, no. 2, pp.87–92, April 1984.

Format of a book reference:

[26] Peck, R.B., Hanson, W.E., and Thornburn, T.H., Foundation Engineering, 2nd ed. New York: McGraw-Hill, 1972, pp.230–292.

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Figures should be black-and-white, clear, and drawn by the authors. Do not use figures or pictures downloaded from the Internet. Figures and pictures should be submitted also as separate files. Captions are obligatory. Within the text, references should be made by figure numbers, e.g. "see Fig. 2."
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Authors are requested to send their manuscripts via electronic mail (preferably) or on a CD by regular mail to the Editor-in-Chief:

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WCNC 2015

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IEEE WCNC is the premier event for wireless communications researchers, industry professionals, and academics interested in the latest development and design of wireless systems and networks. Sponsored by the IEEE Communications Society, IEEE WCNC has a long history of bringing together industry, academia, and regulatory bodies. In 2015, New Orleans will become the wireless capital by hosting IEEE WCNC 2015. The conference will include technical sessions, tutorials, workshops, and technology and business panels. You are invited to submit papers in all areas of wireless communications, networks, services, and applications. The instructions for authors will be posted on the conference website www.ieee-wcnc.org/2015. Potential topics include, but are not limited to:

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- Iterative techniques
- Information-theoretic aspects of wireless communications
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- Propagation models for high frequency channels

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- Multiple access techniques
- Cognitive and cooperative MAC
- Collaborative algorithms
- MAC for mesh, ad hoc, relay, and sensor networks
- Network information theory
- Radio resource management and allocation, scheduling
- Cross-layer design, cross-layer security
- Software defined radio, RFID
- Adaptability and reconfigurability
- Wireless MAC protocols: design and analysis
- B3G/4G Systems, WiMAX, WLAN, WPAN
- QoS provisioning in MAC

Track 3: Mobile and Wireless Networks

- Localization for wireless networks
- Network estimation and processing techniques
- Mesh, relay, sensor and ad hoc networks
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- Wireless multicasting, routing
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SCIENTIFIC ASSOCIATION FOR INFOCOMMUNICATIONS

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Founded in 1949, the Scientific Association for Infocommunications (formerly known as Scientific Society for Telecommunications) is a voluntary and autonomous professional society of engineers and economists, researchers and businessmen, managers and educational, regulatory and other professionals working in the fields of telecommunications, broadcasting, electronics, information and media technologies in Hungary.

Besides its more than 1300 individual members, the Scientific Association for Infocommunications (in Hungarian: Híradástechnikai és Informatikai Tudományos Egyesület, HTE) has more than 60 corporate members as well. Among them there are large companies and small-and-medium enterprises with industrial, trade, service-providing, research and development activities, as well as educational institutions and research centers.

HTE is a Sister Society of the Institute of Electrical and Electronics Engineers, Inc. (IEEE) and the IEEE Communications Society. HTE is corporate member of International Telecommunications Society (ITS).

What we do

HTE has a broad range of activities that aim to promote the convergence of information and communication technologies and the deployment of synergic applications and services, to broaden the knowledge and skills of our members, to facilitate the exchange of ideas and experiences, as well as to integrate and harmonize the professional opinions and standpoints derived from various group interests and market dynamics.

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- contribute to the analysis of technical, economic, and social questions related to our field of competence, and forward the synthesized opinion of our experts to scientific, legislative, industrial and educational organizations and institutions;
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- organize an extensive range of lectures, seminars, debates, conferences, exhibitions, company presentations, and club events in order to transfer and deploy scientific, technical and economic knowledge and skills;
- promote professional secondary and higher education and take active part in the development of professional education, teaching and training;
- establish and maintain relations with other domestic and foreign fellow associations, IEEE sister societies;
- award prizes for outstanding scientific, educational, managerial, commercial and/or societal activities and achievements in the fields of infocommunication.

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