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Optimization of the digital rejection filter

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Abstract. **The digital rejection filter (RF) is offered in the form of the device for subtraction of weighted samples in the non-delayed channel and results of group accumulation of samples in the delayed channel. The RF optimization task is considered with the group sample accumulation in the delayed channel. The optimal relationships between RF parameters and correlation properties of interference are discussed, which corresponds to minimum of interference remainders. The influence of bit grid finiteness of the analog-to-digital converter (ADC) on effectiveness of interference rejection is studied. The expression is suggested for the minimal number of bits, which can be used for a choice of ADC type with account of given losses in effectiveness of interference rejection and required operation speed. The RF adaptation principles under condition of *a priori* uncertainty of interference correlation parameters are discussed. The analysis of the adaptive RF effectiveness is carried out depending on correlation properties of interference and the volume of the learning sample. From relations obtained, it follows that losses in effectiveness of interference rejection, which are caused by adaptation errors, can be restricted in advance by the given value by means of appropriate choice of the learning sample volume.**

Keywords: adaptation, quantization, feedback, learning sample, optimization, bit grid, rejection filter, correlation coefficient, clutter

I. INTRODUCTION

Extraction of the moving target signals on the background of correlated (passive) interference caused by the spurious reflections (clutter) is the one of relevant and difficult tasks of arrived data processing, which are usually solved in the radar systems (RS) of various destinations [1]. The passive interference seriously disturbs the RS normal operation, leading to overloading of receiver path, as well as to masking and, in the end, to moving target signal missing. Protection methods against passive interference depend on the RS type and the probing signal used. This problem is the most effectively solved in so-called pulse-Doppler radars with low off-duty factor of the probing signal, or in RS with quasi-continuous emission, in which the pulses with high repetition frequency are used (up to some tens and even hundreds kilohertz). At that, the off-duty factor does not usually exceed to 20. Selection of moving targets on the background of spurious reflections in such RSs is based on the Doppler effect usage [1].

Processing of received data is performed in the multi-channel system for range and Doppler frequency. Initially, the range gating (selection) is carried out. For each range interval under selection, the set of Doppler filters covers the whole possible range of Doppler frequencies of signals, which are reflected from moving targets. Owing to Doppler frequency difference between the interference and the useful signal, the tracking of the useful signal is performed in Doppler filters, which are interference-free. This provides the best selection of moving targets on the clutter background. At that, we can achieve the unambiguous measurement of the target radial velocity with high resolution and accuracy. The range measurement, however, relates to ambiguity, which can be eliminated by the special method application, which makes the signal processing more complicated [1].

The unambiguous range measurement for large number of targets by simple approaches and with high resolution is achieved in coherent-pulse RS with probing pulses of high off-duty factors, which causes the wide application of such RSs in practice [1]. The low pulse repetition frequency selecting from the condition of unambiguous range measurement leads to close location of the comb spectral components filter, which complicates the moving target signal selection on the background of interference, which power is large compared to the signal. In this case, the main operation of the received signal processing is the rejection of interference spectral components, and RF is the main unit of the appropriate processing system [1].

Utilization of the digital signal processing technique allows implementation of the under-optimal processor on the base of the digital filter for interference suppression, and leaded to realization of the RF with adaptation to the clutter Doppler phase [2-5]. Development of digital methods and devices for digital signal processing proceeds discussions in modern scientific-technology literature.

The parametric *a priori* uncertainty at signal detection on the clutter background makes essential difficulties at effective detection of moving targets. This leads to necessity of the adaptive Bayesian approach [6] utilization based on estimation of unknown interference parameters according to the learning samples, which are formed by samples on adjacent bins on range or the Doppler frequency. The adaptive detection of moving target signals on the clutter background, which is arose by the spurious reflections from the lengthy objects, was considered in [7].

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The point (in range) interference corresponding in duration to signals, which reflected from the point target and which cannot be distinguished from signals reflected from moving targets, requires the special attention. Problems of surveillance radar protection against interference of such a type are considered in [8-11]. In [12], by means of the maximal likelihood method, the estimation algorithm is synthesized for the coefficient of inter-period correlation of the point clutter. The formula for estimation accuracy is obtained, which depends on the correlation coefficient and the volume of learning sample. Digital filters providing rejection of the point interference are of interest.

Digital RF, which suppresses the correlated interference, increases the level of non-correlated interference (proper noises), which leads to losses in SNR and interference/noise ratio. To reduce these losses in RF we offer to use the group sample accumulation, which can be realized with the help of the switched delayed feedback [13].

The structural diagram of digital RF in the form of subtraction device of weighted samples in non-delayed channel and results of group sample accumulation in the delayed channel is offered below. The problem of such RF optimization is considered and optimal relationships are described between RF parameters and correlation properties of interference, which correspond to minimum of interference residuals. The influence of finiteness of the bit grid of analog-to-digital converter (ADC) on effectiveness of interference rejection is considered. The relationship for minimal number of bits is obtained, by which the ADC type can be chosen taking into account the given losses in effectiveness of interference rejection and required operation speed. The principles of RF adaptation under conditions of a priori uncertainty of the correlation parameters of interference are described. The effectiveness analysis of the adaptive RF depending on correlation properties of interference and the volume of learning sample is performed.

II. STRUCTURE AND PARAMETER OPTIMIZATION OF RF

The structural diagram of RF with group sample accumulation with the help of the switched delayed feedback is presented in the Figure 1, where Cal is the calculator of the weighting coefficient a, $\times$ is the multiplier unit, Sw is a switcher, CB is the control block, Σ is a summer, SD is the storage device (for repetition period T), and Cm is a commutator.

Samples of the point interference, which arrive from ADC, in the j-th period (with account of quantization errors) have a form $\tilde{u}_j = u_j + \xi_j$, where ξ_j are samples of the quantization noise. After weighting in the multiplier unit $\times$ of the non-delayed RF channel with the weight coefficient a, we obtain $a(u_j + \xi_j)$. In the delayed channel, taking into consideration the implementation with the help of the first summer Σ, the storage device SD and the commutator Cm of the group sample accumulation with N periods, we have

$$\sum_{k=1}^{N}(u_{j-k} + \xi_{j-k}).$$

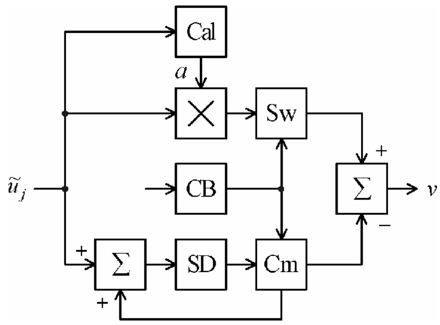

Figure 1. The structural diagram of RF

After closing of the switch Sw (according to the command from CB) and switching of Cm to the input of the second summer Σ of RF, the following quantity is calculated at the output of the second summer

$$v = a(u_j + \xi_j) - \sum_{k=1}^{N}(u_{j-k} + \xi_{j-k}) =$$
$$= au_j - \sum_{k=1}^{N} u_{j-k} + a\xi_j - \sum_{k=1}^{N}\xi_{j-k}.$$

The standard deviation of the RF output is $\sigma_v^2 = \overline{v^2}$. Taking into account the absence of quantization noise correlation with the process under quantization, we obtain

$$\sigma_v^2 = a^2\overline{u_j^2} - 2a\sum_{k=1}^{N}\overline{u_j u_{j-k}} +$$
$$+ \overline{\left(\sum_{k=1}^{N} u_{j-k}\right)^2} + a^2\overline{\xi_j^2} + \overline{\left(\sum_{k=1}^{N}\xi_{j-k}\right)^2}.$$

Assuming that interference characteristics are stationary and tasking into consideration the absence inter-period correlation and the uniform distribution law of quantization noise, we finally obtain

$$\sigma_v^2 = (a^2 + N)\sigma^2 - 2a\sigma^2\sum_{k=1}^{N}\rho(kT) +$$
$$+ 2\sigma^2\sum_{k=1}^{N}\sum_{l=1}^{N-k}\rho[(k-l)T] + (a^2 + N)\frac{\delta^2}{12}, \qquad (1)$$

where σ^2 is the interference standard deviation on the RF input, $\rho(kT)$ are coefficients of inter-period interference correlation, δ is the ADC quantization step.

As we see from (1), effectiveness of interference suppression is determined by coefficients of its inter-period correlation and RF parameters a and N. It is interesting to find the optimal relation between these quantities corresponding to minimum of interference remainders. For this, we write the equation

$$\frac{\partial\sigma_v^2}{\partial a} = 2a\sigma^2 - 2\sigma^2\sum_{k=1}^{N}\rho(kT) = 0,$$

from the solution of which we find out the optimal value of a

$$a = a_{\text{opt}} = \sum_{k=1}^{N}\rho(kT). \qquad (2)$$

Since $\rho(kT) < 1$, we have $a < N$. For the non-fluctuating interference $\rho(kT) = 1$ and $a = N$, which is evident and confirms the trustworthiness of considered transformations.

At exponential function of interference correlation, we have: $\rho(kT) = \rho^k$, where $\rho = \exp(-T/\tau_c)$, τ_c is correlation time. In this case, the optimal value of weight coefficient is

$$a = a_{\text{opt}} = \sum_{k=1}^{N} \rho^k, \quad (3)$$

which simplifies its determination.

At presence of *a priori* information about the ρ value, we can choose in advance the optimal value of a coefficient. Under conditions of *a priori* ambiguity, the a value should be chosen according to the minimax rule orienting on the some average ρ value from the *a priori* expected interval of its variation, or to use the adaptive methods for a choice according to estimated value of the correlation coefficient $\hat{\rho}$, which is determined in the appropriate measuring system according to the operation algorithm [19]. (The adaptive a choice is considered below).

III. CHOICE OF RF DIGIT CAPACITY

Now we consider the influence of the ADC bit grid on effectiveness of interference suppression. Quantization with the δ step leas to increase of non-compensated interference remainders, which have the random character due to inter-period interference fluctuations and the presence of the receiver proper noise. The growth of non-compensated interference remainders may be taken into account by introduction of the discrete quantization noise, which is included in (1) with account of passage through RF.

Let us designate the standard deviation of the interference itself in (1) as

$$\sigma_{v\text{cl}}^2 = (a^2 + N)\sigma^2 - 2a\sigma^2 \sum_{k=1}^{N} \rho(kT) +$$
$$+ 2\sigma^2 \sum_{k=1}^{N} \sum_{l=1}^{N-k} \rho[(k-l)T].$$

Then, losses in effectiveness of interference compensation can be estimated according to the ratio of standard deviation of interference residuals with and without account of the quantization noise:

$$\frac{\sigma_v^2}{\sigma_{v\text{cl}}^2} = \frac{\sigma_{v\text{cl}}^2 + (a^2+N)\delta^2/12}{\sigma_{v\text{cl}}^2} = 1 + \frac{\delta^2}{12} \cdot \frac{a^2+N}{\sigma_{v\text{cl}}^2}.$$

As we see, losses depend on the quantization step δ, RF parameters a and N, and also on the value of reminders of interference itself at the RF output. Ultimately, losses are determined by the ratio of quantization noise and interference reminders at the RF output. However, from the point of view of further processing, the loss value should be considered with account of the proper noise. The proper noise passes through RF in the similar manner as the quantization noise, i.e., its standard deviation σ_{n}^2 varies by $(a^2 + N)$ times. Then, the standard deviation of interference residuals at the RF output takes a form (taking into account the proper noise and the quantization noise):

$$\sigma_{v\text{n}}^2 = \sigma_{v\text{cl}}^2 + (a^2+N)(\sigma_{\text{n}}^2 + \delta^2/12).$$

At that, losses caused by quantization errors correspond to expression

$$\frac{\sigma_{v\text{n}}^2}{\sigma_{\tilde{v}}^2} = \frac{\sigma_{v\text{cl}}^2 + (a^2+N)(\sigma_{\text{n}}^2 + \delta^2/12)}{\sigma_{v\text{cl}}^2 + (a^2+N)\sigma_{\text{n}}^2} =$$
$$= 1 + \frac{(a^2+N)\delta^2}{12[\sigma_{v\text{cl}}^2 + (a^2+N)\sigma_{\text{n}}^2]},$$

where $\sigma_{\tilde{v}}^2$ is the standard deviation of interference and the proper noise (at RF output) without account of the quantization noise.

In this case, losses are determined by the ratio of the quantization noise and a sum of interference reminders and the proper noise at RF output. The largest losses will be at ideal compensation of the non-fluctuating interference, i.e., at $\sigma_{v\text{cl}}^2 = 0$. Then, we have

$$\Delta = \frac{\sigma_{v\text{n}}^2}{\sigma_{\tilde{v}}^2} = 1 + \frac{\delta^2}{12\sigma_{\text{n}}^2}.$$

The loss value now depends on the ratio of the quantization noise and the proper noise. The level of the quantization noise is determined by the dynamic range u_{dr} and the number of bits ν of ADC. At that, the quantization step is $\delta = u_{\text{dr}}/2^{\nu}$. The ADC dynamic range should be chosen for the sum of the signal u_{s}, interference and noise with account of the interference and noise range, not less than $3(\sigma + \sigma_{\text{n}})$, i.e., $u_{\text{dr}} = u_{\text{s}} + 3(\sigma + \sigma_{\text{n}})$. The loss value $\Delta = \sigma_{v\text{n}}^2 / \sigma_{\tilde{v}}^2$ corresponds to the minimal bit number:

$$\nu = \frac{1}{2}\log_2 \frac{u_{\text{dr}}^2}{12(\Delta - 1)\sigma_{\text{n}}^2},$$

according to which the ADC type can be chosen, taking into consideration the given losses Δ and the required operation speed.

At suppression of the fluctuating interference, we must take into consideration the losses caused by the proper noise. These losses value (without account the quantization noise) is determined by equation:

$$\frac{\sigma_{\tilde{v}}^2}{\sigma_{v\text{cl}}^2} = \frac{\sigma_{v\text{cl}}^2 + (a^2+N)\sigma_{\text{n}}^2}{\sigma_{v\text{cl}}^2} = 1 + \frac{(a^2+N)\sigma_{\text{n}}^2}{\sigma_{v\text{cl}}^2} = 1 + \frac{\lambda}{\mu},$$

where $\lambda = \sigma_{\text{n}}^2/\sigma^2$ is the input ratio noise/interference,

$$\mu = 1 - \frac{2a\sum_{k=1}^{N}\rho(kT)}{a^2+N} + \frac{2\sum_{k=1}^{N}\sum_{l=1}^{N-k}\rho[(k-l)T]}{a^2+N} -$$

is the normalized coefficient of interference suppression.

Since $\mu < 1$, the account of the proper noise influence on the interference compensation effectiveness corresponds to loss growth. If the interference is suppressed below the level of the proper noise, we can neglect by interference reminders and at further processing of the moving object signal to consider the proper noise influence only.

IV. RF ADAPTATION

The above-described solution of the RF optimization task with group delayed sample accumulation depending on correlation properties of the point interference allows minimization of its reminders at the RF output and under conditions of *a priori* uncertainty of interference correlation parameters.

During accumulation in the delayed channel of samples with N adjacent repetition periods T and weighting of samples by the weight coefficient a in –non-delayed RF channel, the optimal value $a = a_{\text{opt}}$, determined in general case by (2), while at the exponential function of interference correlation – by (3), corresponds to minimum of reminders.

At presence of *a priori* information about the ρ value, the optimal value of a may be chosen in advance. Under conditions of *a priori* uncertainty it is necessary to use adaptive methods for the a value choice.

In accordance with the adaptive Bayesian approach, the unknown quantities $\rho(kT)$ are replaced by their consistent estimations $\hat{\rho}(kT)$ [6]. At known form of the correlation function, it is enough to find estimation of the correlation coefficient $\hat{\rho}$. Then, in the case of exponential correlation function, we have for estimated value of the optimal weight coefficient:

$$\hat{a} = \sum_{k=1}^{N} \hat{\rho}^{k} . \tag{4}$$

As the $\hat{\rho}$ estimation, we should use estimates of maximal likelihood (EML) obtaining on the base of both direct and indirect algorithms of sampled values' processing u_j, $j = \overline{1, n}$. Direct algorithms contain the multiplication operation of initial samples [12]:

$$\hat{\rho} = \sum_{j=2}^{n} u_{j-1} u_j \Big/ \sum_{j=2}^{n} u_j^2 .$$

Indirect (summing-subtracting) algorithms are free from this operation:

$$\hat{\rho} = 1 - \frac{\sum_{j=2}^{n} (u_{j-1} - u_j)^2}{\sum_{j=2}^{n} (u_{j-1}^2 + u_j^2)} .$$

Modified algorithms deal with summed (subtracted) values:

$$\hat{\rho} = \frac{\sum_{j=2}^{n} [(u_{j-1} + u_j)^2 - (u_{j-1} - u_j)^2]}{\sum_{j=2}^{n} [(u_{j-1} + u_j)^2 + (u_{j-1} - u_j)^2]} .$$

Calculation of correlation coefficient $\hat{\rho}$ estimation according to one of presented algorithms and the optimal weighting coefficient on algorithm (4) is performed in the calculator Cal (see Figure 1).

From EML consistency condition [14]

$$P\{\lim_{n\to\infty} \hat{\rho} = \rho\} = 1$$

it follows that with growth of learning sample volume n, the $\hat{\rho}$ estimation with unit probability converges to the true value of parameter under estimation. Hence, EML usage (instead unknown parameters) leads to adaptive algorithms, which have the convergence property to the appropriate algorithms at known parameters.

At adaptive interference compensation, the RF output value is

$$v = \hat{a} u_j - \sum_{k=1}^{N} u_{j-k} .$$

The standard deviation of the RF output quantity is

$$\sigma_v^2 = \overline{v^2} = \overline{\hat{a}^2 u_j^2} - 2\hat{a} \overline{\sum_{k=1}^{N} u_j u_{j-k}} + \overline{\left(\sum_{k=1}^{N} u_{j-k} \right)^2} .$$

Because of the fact that determination of the $\hat{\rho}$ estimation is based on the averaging of n samples, the mutual correlation of the $\hat{\rho}$ estimation and the separate sample u_l is practically absent. From these, it follows that the mutual correlation of quantity $\hat{a}$ and u_l is absent. Then, assuming that interference characteristics are stationary, we obtain

$$\sigma_v^2 = (\overline{\hat{a}^2} + N)\sigma^2 - 2\bar{\hat{a}}\sigma^2 \sum_{k=1}^{N} \rho(kT) +$$

$$+ 2\sigma^2 \sum_{k=1}^{N-1} (N-k)\rho(kT) , \tag{5}$$

where σ^2 is the interference standard deviation at RF input.

Using asymptotic properties of EML $\hat{\rho}$, we perform the appropriate averaging in (5). Equation (4) can be represented in the form of functional transform $\hat{a} = f(\hat{\rho})$. Let us consider the linear approximation of the $\hat{a} = f(\hat{\rho})$ function in vicinity of ρ in the form

$$\hat{a} = a + a'(\hat{\rho} - \rho) ,$$

where

$$a = f(\rho) ,\ a' = f'(\rho) = \partial f(\rho) / \partial\rho .$$

According to (3), it is easy to find

$$a' = b = \sum_{k=1}^{N} k \rho^{k-1} .$$

Taking into consideration the asymptotic normality of the $\hat{\rho}$ estimation distribution with the mean value ρ and the standard deviation $\sigma_{\hat{\rho}}^2$, we obtain

$$\overline{\hat{a}^2} = \overline{[a + b(\hat{\rho} - \rho)]^2} = a^2 + b^2 \sigma_{\hat{\rho}}^2 . \tag{6}$$

The standard deviation $\sigma_{\hat{\rho}}^2$ is determined in accordance with the expression obtained in [12]:

$$\sigma_{\hat{\rho}}^2 = \frac{(1-\rho^2)^2}{(n-1)(1+\rho^2)} .$$

We would like to note than for direct and indirect algorithm, the measurement accuracy is the same [12], which justifies their equivalence from the point of view of measurement accuracy.

Taking into account equations (5) and (6) and the obvious equality $\overline{\hat{a}} = a$, we finally obtain for interference suppression by the adaptive RF:

$$\frac{\sigma_v^2}{\sigma^2} = a^2 + b^2\sigma_{\hat{\rho}}^2 + N - 2a\sum_{k=1}^{N}\rho(kT) + $$
$$+ 2\sum_{k=1}^{N-1}(N-k)\rho(kT). \quad (7)$$

Equation (7) allows estimation the effectiveness of the adaptive RF as a function of correlation properties of interference, the volume of learning sample and RF parameters. As wee see, the adaptation errors determining by the $\sigma_{\hat{\rho}}^2$ standard deviation value, increase the interference reminders at RF output, resulting in appropriate losses in effectiveness of its suppression. Calculation show that at $n \geq 4$, losses do not exceed a fraction of decibel in the wide range of interference parameters variation.

V. CONCLUSION

Optimization of RF parameters in accordance with correlation properties of fluctuating interference allows minimization of their reminders at the RF output, and the proposed choice of ADC digit capacity allows limitation of losses, caused by quantization, by the required value.

Adaptation of the offered rejection filter allows minimization of reminders of the correlated interference at its output under conditions of parametric *a priori* uncertainty, while the losses caused by the adaptation errors in the effectiveness of interference suppression, as it follows from equation obtained, can be limited by the given in advance value by means of appropriate choice of the learning sample volume.

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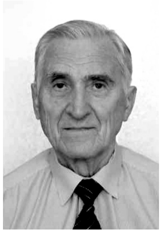

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Ethernet with Time Sensitive Networking Tools for Industrial Networks

Csaba Simon, Miklós Máté, Markosz Maliosz and Norbert Bella

Abstract — **In currently deployed networks the time critical and/or real time traffic is sent over dedicated networks, requiring the operation of a separate infrastructure. This is especially true for Industrial Networks, which use technologies and protocols that are designed particularly for that purpose. The IEEE 802.1Q Time-Sensitive Networking (TSN) task group introduced a set of standards by defining QoS mechanisms, also known as TSN features, so that standard Ethernet networks could provide precise timing for critical flows. We have implemented two mature TSN features, frame preemption and time gated queuing, in a simulator, and on multiple network topologies we have evaluated the end-to-end delay and packet delay variation as the main QoS metrics and important design considerations in industrial networking setups. Our simulation results have shown that the QoS guarantees provided by TSN are strong enough for industrial use cases, but we have also identified some design and configuration pitfalls that TSN-adopters need to be cautious about.**

Index Terms* — *Industrial Networks, IoT, Ethernet, Time-Sensitive Networking

I. INTRODUCTION

THE latest developments in manufacturing technology and the globalization of world economy increased the competition among manufacturing sites at global level. The spread of smarter devices (machines) and the decreasing cost of computational resources enabled the innovation of manufacturing processes. Industrial actors have to follow the rapid changes in customer demands and this high flexibility must be supported by the plant infrastructure. The Industry 4.0 initiative, catalyzed by the German Federal Ministry for Economic Affairs and Energy [1] summed up the digitization trends in manufacturing. Industry 4.0 has also been acknowledged by the European Union (EU) to set a framework for the required research and development actions to be taken along the road of the digitization of manufacturing [2]. Since then the Industry 4.0 has been enumerated among the foundations of the European Commission's industry-related initiative of the Digital Single Market, which forms the industrialization policies in one of the world's leading industrial ecosystem [3].

The realization of the Industry 4.0 goals towards the digitization of the industry also puts a great pressure on network solution providers. Traditionally the networks connecting the process controllers, machines and sensors have been using specialized equipment and were expensive and lacked adaptability. Whereas industrial networking and Industrial Ethernet solutions in particular are available for many particular use cases, the interaction and cooperation among these solutions is not solved [4]. Moreover, the adaptation of these existing solutions to some of the needs is cumbersome, too [5]. As digitization of the real time manufacturing process has strict requirements in terms of timing and data rate, the provision of proper transport/networking solutions is crucial to its success. There is a growing consensus among actors in the field of industrial networking that standard Ethernet should be used to provide the much needed one-size-fits-all solution.

Using Ethernet in an industrial environment is nowadays realized by *Industrial Ethernet* that is the use of Ethernet with protocols and/or modified MAC (Media Access Control) layer to provide determinism and real-time control (see Section II). Our paper promotes an emerging alternative based on standard Ethernet with the enhancements added by Time-Sensitive Networking features. The use of standard Ethernet (or "vintage Ethernet", as referred to in [4]) for industrial networking offers the promise of cheap operation, supported by the economies of scale resulted from the huge installment base and mass-scale production, large pool of specialists and low training costs, a well understood behavior tested in various deployment scenarios and over all phases of its lifecycle. As matter of fact, nowadays Ethernet is the de-facto single standard for layer 2 technology in enterprise networking and data centers [6][7], and a powerful alternative in the aggregation and access domains of the telco networks [8]. Ethernet also enables convergent networking, where various types of traffic are transported over the same infrastructure. In the context of industrial networking this means that low priority (e.g., best effort) traffic is carried on the same transport where high priority control traffic is forwarded. On top of that, due to this property, the use of standard Ethernet instead of various Industrial Ethernet standards also makes these deployments future proof, because it enables any new applications and services operating on this common infrastructure.

All the above considerations highly motivate both business decision makers and network architects to adopt Ethernet for industrial networks. Still, certain real-time manufacturing applications are safety-critical and have strict Quality of

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Service (QoS) requirements in terms of availability, packet loss and delay, not supported by the standard Ethernet. Current installed base and current product lines of the vendors offer further arguments against this change. Nevertheless, latest evolutions in Ethernet standard expected to be embraced by both vendors and system integrators in the near future strengthens our expectation that the networking and automation industry are at a turning point, business-side demands and technical expectations making this change to happen. Looking at the standardization activities concerning Ethernet, the most relevant advances are made within the IEEE 802.1 Time-Sensitive Networking (TSN) task group [9]. TSN mechanisms address all critical aspects of industrial applications requiring strict QoS, synchronization, reliability and deterministic delay (see Section III for further details). Note that several use cases are expected to deploy TSN mechanisms (5G, vehicular, IoT, etc.), but in this paper we keep our focus solely on industrial networking. Since TSN features are defined as amendments to the main IEEE 802.1Q standard [10], major vendors will support it in the near future (e.g., in industrial networking nodes by TTTech [11] or Cisco [12]) and industrial networking solution providers (e.g., National Instruments [13], Belden [14]) will propose integrated solutions to manufacturers.

Based on the above argumentation we predict that in the near future industrial networking will be based on standard Ethernet (which also includes TSN features). Knowing that industrial traffic has complex requirements the introduction of standard Ethernet in industrial networks is not straightforward, involving more engineering effort than just replacing current networking nodes. Before such change happens we should understand how the Ethernet network will accommodate the industrial traffic.

We use a network topology and traffic mix specific to industrial networks to illustrate the way how standard Ethernet can support industrial applications. Building on the results of our simulation experiments we explain some issues that might occur in Ethernet based industrial networks, which the designers of such networks should be aware of. One goal of our paper is to show by simulations the efficiency of using different TSN features to protect the express traffic against the low priority (best effort) traffic. Another goal of our paper is to highlight the interaction between multiple express flows, because TSN features will protect the express flows from the low priority traffic, however using them it can result in race conditions between the frames from different express flows causing delay variations.

The rest of this paper is organized as follows. Section II gives an overview of the most common Industrial Ethernet solutions. Section III summarizes the two TSN features (preemption and time-gating) we used in our simulations. Section IV presents our simulation setup and the results of the simulations, and in section V we draw the conclusions.

II. INDUSTRIAL ETHERNET SOLUTIONS

In the field of industrial control and monitoring technology there has been an ongoing transition from vendor-specific and other specialized systems to Ethernet. Ethernet have evolved way beyond its original CSMA/CD-based bus architecture in the last couple of decades. Its new features and increased speed make today's switched Ethernet a reliable, cheap and versatile telecommunication medium. With an array of proprietary extensions it is possible to deploy it in a factory.

There are three levels of quality requirements in industrial networks. The first level is when there is only best-effort traffic: the only requirement is a low packet loss rate, but there are no timing requirements. The second level is the soft real-time systems: here the requirement is that the packets must be delivered within 10 ms with the lowest delay variance possible, and no out-of-order delivery is allowed. The third level is the hard real-time systems: the packets must be delivered within 1 ms, and there is even less tolerance for delay variance than on the previous level.

Industrial Ethernet is the common name for network technologies that are Ethernet-based solutions for industrial control, monitoring and automation systems. They include extensions to standard Ethernet that enable deterministic delay, high reliability and real-time response capability. These equipment are also hardened for the potentially harsh environmental conditions of a factory, but the hardware specifications are not in the scope of this paper. In the followings we provide a non-exhaustive overview of Industrial Ethernet technologies.

Perhaps the most widely known Industrial Ethernet solution is PROFINET (PROcess FIeld NETwork) [15]. The PROFINET IO system consists of one Controller node, and a number of Device nodes connected by Ethernet links. PROFINET IO RT provides soft real-time communication with cycle times between 5 ms and 10 ms. This is essentially best effort with optimized software stack for fast processing. Without time synchronization the frames sent by the slave nodes may collide; thus, star topology is recommended. PROFINET IO IRT is an isochronous, hard real-time variant. With precise time synchronization short cycle times can be reached; the specification supports 1 ms and 250 us. When the IRT data does not fill the whole cycle, the remaining time can be allocated to RT or other TCP/IP data. Both RT and IRT supports line, star and ring topologies, but the timings must be tuned according to the number of devices and cable lengths.

EtherNet/IP adapts the Common Industrial Protocol (CIP) to Ethernet [16]. Its communication model is based on a producer/consumer model, a message is only delivered to the nodes that subscribed to it. This is, however, implemented as broadcast transmission and filtering at the receivers. The nodes are aligned in a ring topology; the ring manager node verifies the connectivity every 400 microseconds by polling the nodes in the ring, and reconfigures the network if it detects an error. The protocol uses TCP connections between the nodes for configuration and management functionalities, while the I/O traffic is sent over UDP.

CC-Link IE was originally developed by Mitsubishi Electric [17], but later it was released as an open standard maintained by the CC-Link Partner Association. It has application profiles for communication between process controllers, field I/O, and motion control. The nodes form a ring topology of at most 120 nodes, and their communication pattern is governed by token passing supervised by a master node. The physical layer used is 1 Gbps Ethernet on fiber or copper, but the protocol uses a special MAC. Some versions of CC-Link also support star and bus topologies in addition to the ring.

Sercos III is the third generation of the Sercos automation bus [18]. It is based on standard Fast Ethernet (100 Mbps) with EtherType 0x88CD, and the network topology can be either a bus or a loop. The communication is cyclic, the length of one cycle can be set between 31.25 us and 65 ms, depending on the number of devices. Part of the cycle is reserved for the real-time traffic of Sercos, while the rest is freely available to other traffic, such as TCP/IP. Sercos also synchronizes the devices in a network to the master clock with 1 us accuracy.

As a summary we can conclude that these protocols use a master-slave hierarchy and periodic polling to achieve deterministic delays and fair channel arbitration. The specifications also pin the speed of the underlying Ethernet interface, which is good for determinism, but it can limit the scalability of the network.

Based on the publicly available market research data over the last decade among all the Industrial Ethernet technologies the PROFINET is among the most successful solutions and has the most dynamic growth [19][20]. Due to the popularity of this protocol we will use it as a reference networking scenario in this paper, as detailed later in Section IV.

III. Time-Sensitive Networking

Ethernet is envisioned to be used as single standard in Industrial Networking, however the current standard Ethernet without the TSN features does not offer QoS guarantees required by the industrial applications. Historically the QoS support in Ethernet has been mostly limited to priority queueing. The VLAN-tag defined in IEEE 802.1Q includes a 3-bit field called Priority Code Point (PCP), and IEEE 802.1p defines the meanings of these 8 priority levels. The transmission selection logic in an Ethernet switch uses separate queues for each priority, and a priority-based selection algorithm [10]. A dedicated task group (TG) called Audio Video Bridging (AVB) was established to expand the IEEE 802.1 bridging features for better QoS support, which later was renamed to become the IEEE 802.1 Time-Sensitive Networking (TSN) Task Group to extend the scope to industrial and automotive fields [9].

The TSN TG is specifically working on enhancing the standard Ethernet bridging to support time-critical traffic by defining standardized solutions for QoS mechanisms to reach precise timing for the priority traffic in Ethernet networks [9]. The task group is still active and more mechanisms are expected to be defined in the following years. In the remaining part of this section we succinctly present the mature TSN features. Later in our work we used only those that we considered that support the industrial applications.

Time synchronization between the switches is an important feature of TSN. The Precision Time Protocol (PTP) as defined in IEEE 1588 was adapted to Ethernet in IEEE 802.1AS, and TSN extended it in IEEE 802.1AS-Rev [21]. This protocol can achieve sub-microsecond accuracy, which is sufficient for most TSN applications. Synchronization might not be perfect and applied a stochastic model to examine the effects of this imprecision.

IEEE 802.1Qcc Stream Reservation defines the layer 2 level reservation procedures [22]. In typical industrial networking scenarios the resource reservation for communication is done before the start of the industrial applications. Therefore we are not detailing this standard in this paper.

IEEE 802.1CB proactively replicates packets to offer redundant transmission and it manages the handling of redundant packets to make this process transparent to the application [23]. This Frame Replication and Elimination for Reliability (FRER) mechanism increases the packet delivery ratio, which is useful in certain control protocol scenarios, if the recovery from an equipment failure is unacceptable. FRER essentially provides 1+1 protection for streams. In most of the industrial networking scenarios this requires the deployment of a second “shadow” network, which might be feasible for specific use cases. In our investigations we focus on such optimized deployments where only single streams are sent in the network.

A new mechanism of TSN that is very different in nature compared to other ones standardized by the IEEE 802.1 work group is the frame preemption, which is standardized in IEEE 802.1Qbu [24] and IEEE 802.3br [25]. With this mechanism the transmission of a lower priority frame can be interrupted in favor of transmitting a higher priority one. The transmission of a frame on a point-to-point Ethernet link was traditionally thought of as an atomic operation. Interrupting it was seen as violation of a basic, yet unwritten Ethernet principle by many professionals. Nevertheless, the power of preemption for providing bounded delay variance is very convincing.

Preemption works as follows. The 8 priority queues are divided into two groups: the highest priority queues are labeled as express, and the rest are preemptable. When an Ethernet frame arrives in an express queue, and a preemptable frame is being transmitted, the transmission is interrupted, the remainder of the frame is put aside, and the transmission of the express frame is started. When the transmission of the express frame is finished, and no other express frame is waiting in the queue, the transmission of the preempted frame is resumed. One transmission can be interrupted several times.

By using preemption the delay and delay variance of time-critical traffic can be greatly reduced without waiting for the end of the transmission of a potentially large frame ahead of an express frame. There are limitations to the efficiency of preemption though. The transmission can only be interrupted on byte-boundaries. The MAC also must send a CRC inserted into the tail of the frame, and wait an inter-packet gap (IPG) before a new transmission can be started. This means that there is always a non-zero preemption latency. The minimum size of an Ethernet frame is 64 bytes; thus, the express frame suffers higher preemption latency if it arrives at the beginning or at the end of the transmission of the preemptable frame.

The worst case happens when the preemptable frame is too small, and cannot be cut into two pieces of at least 64 bytes each [24]. Note that express frames cannot be preempted; thus, the interference between time-critical flows cannot be handled with this technique.

The other major TSN mechanism for express traffic is the time-aware shaper standardized in IEEE 802.1Qbv [26]. It introduces a timed gate for each of the 8 priority queues, the opening and closing of these gates is governed by a predefined gate control schedule. When a gate is closed, the corresponding priority queue is barred from the transmission selection algorithm.

If the arrival times of the express frames at a switch are known, then this tool can completely eliminate the latency caused by interfering traffic. In anticipation of the express frame the gates of all other priority queues are closed, and when the express frame is expected to have left the switch, the gates can be opened again. This sounds simple at first, but there are several pitfalls when setting up the gate timings. If the express frame arrives outside of its expected interval, it is not protected from the interfering traffic. If the express frame doesn't arrive at all, because the flow hasn't started yet or it already ended, the other flows were stopped uselessly.

Most of these problems can be traced back to incorrect time synchronization among the devices in the network. Time-gating can only function properly, if all the devices are synchronized to a master clock. Time gating can be protected from the synchronization uncertainty by increasing the expected intervals with the upper bounds of the time synchronization errors.

The above two TSN mechanisms can be combined into a so-called protected window with guard band. In this mode the preemption is triggered by the gate timing instead of the arrival of the express frame. In anticipation of the express traffic its gate is opened, and at the same time a preemption signal is sent to the MAC. When the express frame arrives, the way is already cleared for it. The advantage of this method over simple time-gating is higher link utilization: without preemption support the transmission of a lower priority frame cannot start, if it won't finish before its gate closes.

IV. SIMULATIONS

A. Simulation Scenarios

We prepared several simulation experiments to find answers to the questions asked in Section 1. The network topology of our simulations is based on the topology observed in a real PROFINET IO RT deployment investigated by Ferrari et al. [27]. The core switches are connected in ring topology, and the IO devices are connected to the core switches via cascaded buses by lines of drop switches. Maximum 9 IO devices are cascaded over one bus, but multiple such buses may be plugged into a core switch. All devices are controlled by one IO controller, which is directly linked to one of the core switches. For performance reasons we only simulated part of this topology, but taking care to keep all the important node and traffic types. We will refer to this topology as the cascaded one. Starting from this topology we also created another two topologies to better understand the performance of TSN.

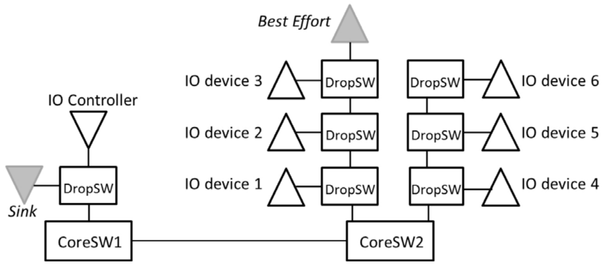

Fig. 1. The simulated network with cascaded topology

Our second topology is a slightly modified version of the cascaded one. In this topology the IO devices are all connected to their respective core switches directly, without forming a bus. This topology corresponds to the usual switched Ethernet topologies and not to the usual industrial topologies. We will refer to this one as the star topology.

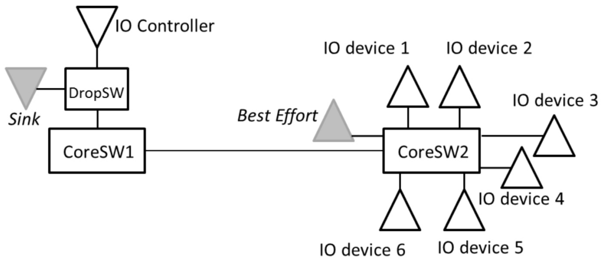

Fig. 2. The simulated network with star topology

In our third topology a series of IO devices are connected into a ring, one device per each switch, forming a ring topology. In practice multiple devices might be connected to the switch. The idea behind this arrangement is that there are few devices attached to the core switches and the ring is expanded instead.

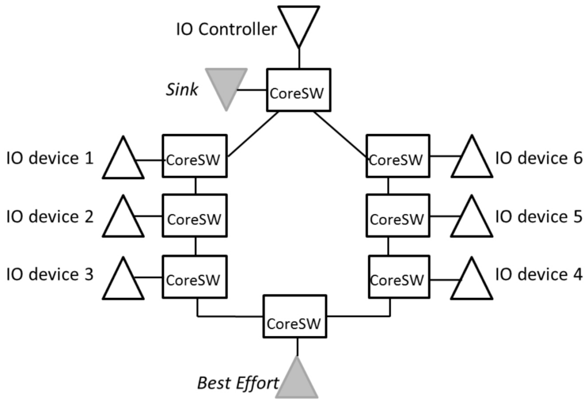

Fig. 3. The simulated network with ring topology

This topology is formed with a different mindset compared to the star topology, because the latter tries to channel as many devices possible to the core switch. The redundancy that the ring provides is very important in factories, where high reliability is absolutely required. Note that in the cascaded topology if the bus is detached from the core switch, all the devices from it are disconnected from the controller.

Fig. 1, Fig. 2 and Fig. 3 present the logical structure of the three topologies implemented in our simulation tool. In a large real deployment there would be hundreds of devices in a network, but we had to limit our simulations to 6 IO devices and one low priority traffic generator (the Best Effort source that send frames to the Sink). According to TSN terminology the end devices are called *end stations*, but in our industrial setup they are denoted as *IO devices*. In all of the three examined topologies we could examine the conflict situations when multiple control flows race for the same output link, causing QoS degradation (packet delay variation).

In all three networks the core switches are connected by 100 m long 1 Gbps links, and all the other links are 10m long and have 100 Mbps link rate. The serialization delay of 1bit over the 1 Gbps link is 1 ns and over the 100 Mbps link is 10 ns. The propagation delay is 5 ns/m.

In the case of cascaded topology all the IO devices are linked to a small switch, called drop switch, which in practice is integrated with them. In both cascaded and star topologies the sources send the frames at around the same time with only a small time difference (in the order of ns). Thus, the flows originated from devices that are at equal distances from the core switch will arrive at around the same time and with precise timing this small time difference makes the servicing order deterministic between the frames of these flows. However, with imprecise timing these frames are in race condition for the output link.

When designing the traffic model we attempted to recreate the worst-case situation. The control traffic is Constant Bit Rate (CBR) traffic, with 1 ms cycle time (the time between two successive frames). This 1 ms value provides hard real time assurances in Industrial Ethernet [28]. Unless stated otherwise, we used frames with MTU (Maximum Transmission Unit) of 1500 bytes, because that is the maximum frame size allowed by Ethernet. These large frame sizes are the worst case, because smaller frames are less prone to collisions and have lower serialization delays over the same link rates. Best Effort traffic has 1500 byte frames, but are sent with a different cycle time (1.2 us) to have race conditions with different control flows during the simulation time, thus we could observe every possible interference pattern between the high and low priority traffic. The control traffic between the industrial devices and the controller is the prioritized one, which is called in TSN terms the express traffic. The other, low priority traffic is considered to be best effort (BE) traffic. The switch model in the simulator is a generic switch with infinite backplane switching capacity and with switching delay value of 1.5 us, which models a fast enterprise switch [29].

We required frame-level analysis for the experiments; therefore the simulation environment must be a frame-level tool, providing the Ethernet stack, preferably extensible in a modular fashion. The OMNeT++ tool [30] with its INET framework [31] satisfies this requirement. The existing Ethernet model is easily extensible. We implemented the TSN features for our investigations, such as time gates and preemption support.

B. Simulation Results

Our goal is to evaluate the effectiveness of the usage of selected TSN features by analysing the end-to-end delays of the frames in the network. In order to assess the delay variation we monitored the Packet Delay Variation (PDV). PDV is the commonly used term for packetized traffic, even if in our case at layer 2 we observe the delay variation of frames. The PDV is computed as the difference between the highest and lowest end-to-end delay value:

$$PDV = \max(\textit{end-to-end latency}) - \min(\textit{end-to-end latency}) \quad (1)$$

Also design guidelines can be inferred from the observed results, e.g., regarding the timing configuration of the time gated queues.

1) Assuming Precise Traffic Source Timing

For the first set of experiments the traffic sources send periodic data in cycles, and here we assume that the sending is precise, thus exact timing without any variations is applied in the simulator.

In our first experiment the sending time of the express frames are set such as they will leave the ring switch in a deterministic way, resulting in fixed end-to-end delays (i.e., zero PDV).

Fig. 4 plots the end-to-end delays of the frames of all the 6 express flows with different colors. Each point of the chart corresponds to one express frame, and for the each flow the end-to-end delay is the same for all of its frames. The chart shows a repetitive pattern, because all the frames during each cycle are scheduled to be sent at around the same time, and the small time differences yield deterministic arrival to CoreSW2.

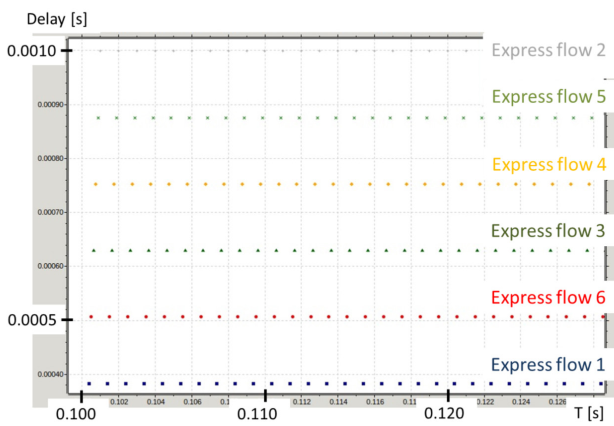

Fig. 4. Six express flows in a network with star topology

When BE traffic is enabled and there are no TSN mechanisms deployed the frames within express flows suffer different end-to-end delays, resulting in non-zero PDV (see Fig. 5). The reason for this is that while the BE frames are served by the switch, the express frames need to wait in the queue, and they are therefore delayed. When an express frame is delayed, another express flow can take the “place” of this delayed frame. On the figure this looks like the frame in question is “shifted”, as the three arrows show in zoomed in part. It can also be seen that BE has a repetitive nature, but with a different cycle time and because of this it delays express frames at different positions in the back-to-back train of the 6 express frames, resulting in different end-to-end delays.

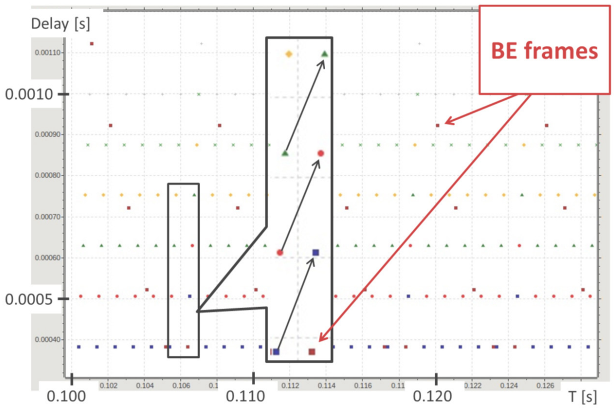

Fig. 5. The effect of BE frames on express traffic (star topology)

The effect of BE flows heavily depends on the topology and original timing of the express flows. We illustrate this in Fig. 6, where the pattern is slightly different compared to Fig. 5, because the arrival of the two sources closest to the CoreSW2 get through the switch before the BE frame would affect them. Thus, only the remaining four express frames have non-zero PDV.

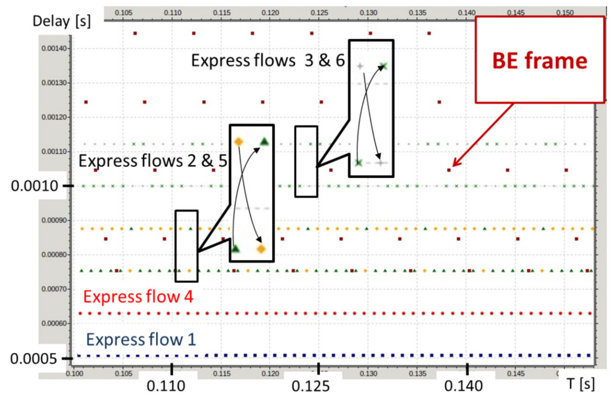

Fig. 6. The effect of BE frames on express traffic (cascaded topology)

In order to avoid the delays caused by the interfering BE frames, first we applied the preemption mechanism (see Fig. 7). The numerical results are shown in Table I. The PDV = 0.15 us for star topology, which corresponds to the worst case (i.e., largest) preemption delay. Note that for the ring and the cascaded topologies the PDV is 123.04 us, a value that is three orders of magnitude larger than the preemption delay. The reason for this is that in the worst case the preemption delay is large enough to "shift" the preempted frame behind the express frame from a different control flow, and the PDV is

$$PDV = preemption\ delay + serialization\ delay(the\ other\ express\ frame) \quad (2)$$

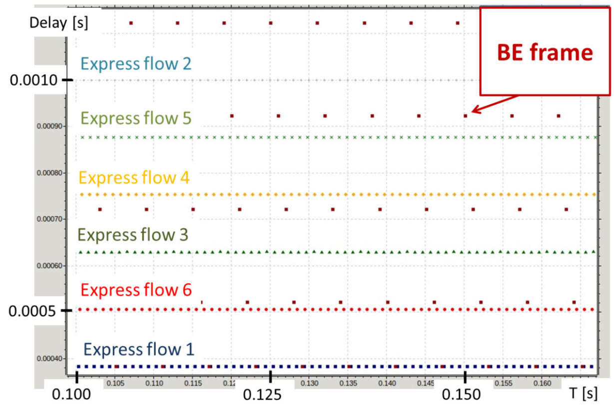

Fig. 7. The BE and express flows in a star topology network with activated preemption feature

Note that in this case the express frame size is the largest one, equaling 1500 bytes, thus, we measure the highest PDV possible. These experiments show that the choreography of the express frame arrivals is fragile: even very small delays may result in large PDVs. During the design phase it is not enough to evaluate the effect of race conditions at a single hop. Uncertainties induced by low priority traffic at a given hop might result in more race conditions farther away along the path. This can be avoided if we increase the gap between the arrival of the express frames.

TABLE I
HIGHEST PDV VALUES FOR ALL THE SCENARIOS WITH EXPRESS FRAMES OF 1500 BYTES

Topology	Express only (us)	Both express and BE (us)	Preemption (us)	Time gating (us)
Cascaded	0,00	123,04	123,04	0,00
Star	0,00	123,04	0,15	0,00
Ring	0,00	212,47	123,04	0,00

We also applied the time gated queuing to all three scenarios (see the last column of Table I). We calculated and applied the proper time gating configuration for each switch to let the frames of express flows through the network without getting into race conditions, and the resulting PDV is 0 for all topologies. Note that this perfect result was achieved in a setup without any variation of the source sending intervals, or of the switching delay values. This shows that in a well synchronized network time gating is able to protect the express traffic from the potential uncertainties caused by the BE frames.

a) The effect of link rate of the IO controller

In the followings we analyse the effect of the link rate at the controller (e.g., the output link of CoreSW1 towards the IO controller in Fig. 3). Let us start with the network arrangement investigated above. Fig. 8 shows the frame positions within a cycle as seen at the output links of the input of the CoreSW2, at the output of the CoreSW2 and at the output of CoreSW1 in the case of ring topology. The frame sizes are 1500 bytes and the source sending times are set in such a way that they arrive back-to-back to the CoreSW2. The input link rates of CoreSW2 and the output link rate of CoreSW1 are 100 Mbps, the core link between the core switches is 1 Gbps.

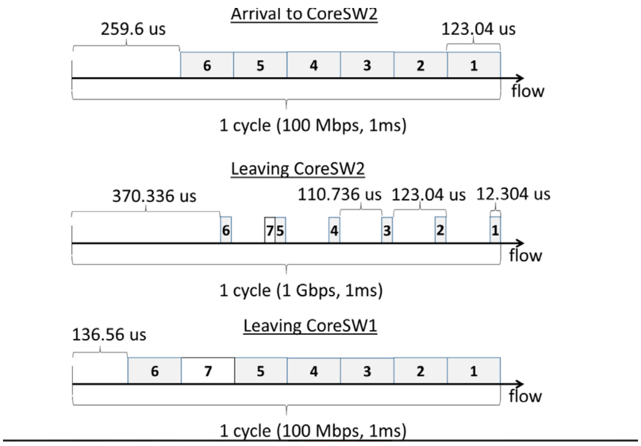

Fig. 8. Frames of racing express flows seen at different hops of the star topology

Even if the frames arrive back-to-back at CoreSW2, since the output link rate of CoreSW2 is 10 times faster and subsequently the serialization delay of each frame is 10 times shorter, there will be gaps between them. In this gap 9 similar express frames, which come from a different direction, may get inserted. For the sake of easier understanding we illustrated the insertion of only a single additional frame 7 right after frame 5 at the output of the CoreSW2. On the 100 Mbps controller link the serialization delays of each frame increase again to the 123.04 us value, and frame 7 will shift frame 6. This results in a PDV of frame #6 equal to this serialization delay.

Now let us evaluate the effect of increasing the link rate of the controller link to the link rate of the core link. Then both links rates will be 1 Gbps, the serialization delays of the frames will not change at the core switch, thus the gaps between the frames will remain the same. The possibility for other frames to be inserted will still be open (e.g., the frame #7 can be inserted between frames #5 and #6), but they will not cause any further delays. This means, that the PDVs of the observed frames will not be further increased.

We made a simulation experiment where the control link rate was 1 Gbps to show that the pacing of express frames remain unaltered by the insertion of a new express frame, as shown in Fig. 9. For this experiment we used the cascaded topology, in which we increased the control link rate to 1 Gbps and we kept only two express flows. We scheduled their arrival at CoreSW2 back-to-back, as it can be seen in the left hand side of Fig. 9. Then we sent a third express frame that was scheduled to leave the CoreSW2 right after express frame 1. It can be seen on the right hand side of the figure that the pacing of frames 1 and 2 remains the same.

Moreover, one must not forget that all the controlled IO devices send their traffic to the controller, thus, the controller link rate has to accommodate all the control traffic. If the

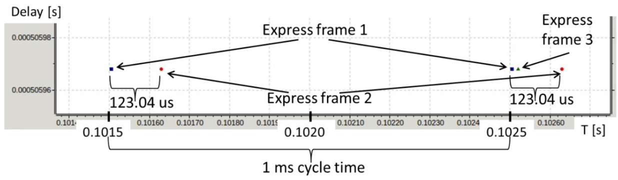

Fig. 9. Inserting a third frame between two express frames (1 Gbps control link)

control link rate is smaller than the core link rate, then it might unnecessarily limit the number of controlled IO devices. In this example with frames of 1500 bytes MTU and 1 ms cycle this upper limit is 8 devices, which is unpractical. An alternative solution would be to lower the frame size: in the same scenario a 150 bytes control frame would allow the control of 81 devices. As a conclusion, the control link rate should be treated as a bottleneck with high impact on the overall capacity of the system during the design of the industrial network.

b) Preemption of small express frames

If the industrial express frames are small, smaller in transmission time than even the preemption delay, then in certain situations the express frames change their order of arrival just because of the preemption delay.

We have set up a small simulation experiment to show this effect, using a cascaded topology with only two express traffic sources and one BE (see Fig. 10). The size of the BE frame is 123 bytes with header, thus it cannot be split into two fragments of 64 bytes, and the preemption delay will take the worst case value, which is the serialization delay of the 123 bytes frame. The link rate at the core is 1 Gbps, all other links are 100 Mbps. The traffic scenario in this network is shown in Fig. 11.

If there is no BE traffic, then express frame 1 is scheduled to

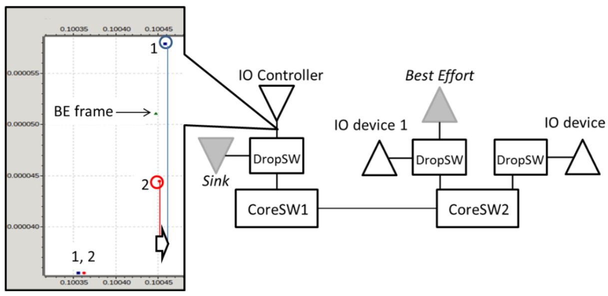

Fig. 10. Evaluating the effect of preemption on very small frames

arrive just before express frame 2 to Core_SW2 (see the upper half of Fig-traffic). When BE traffic is enabled the BE frame is scheduled to arrive to the DropSW on Fig-small just before the express frame 1. When DropSW wants to send express frame 1, the BE frame is already under transmission. Thus, there will be an unsuccessful preemption attempt on the BE frame, and frame 1 gets delayed. Due to this delay express frame 1 will arrive to CoreSW2 later than express frame 2, and thus their order will be swapped, resulting in the output illustrated in the lower half of Fig. 11.

The resulting end-to-end delay values for the case of small express frame size (72 bytes) are plotted in the left hand chart of Fig. 10. The express frames change their order of arrival, and express frame 1 has larger PDV than express frame 2.

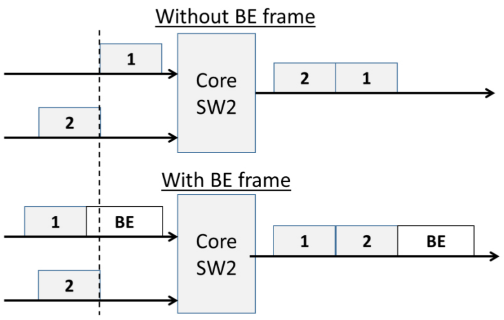

Fig. 11. Preemption scenario with small express frames

We present the resulting PDV values for both cases in Table II. It can be seen that if the express frame size is greater than or equal with 123 bytes, then the PDV is the same for all frames, because there was no change in the order of arrival.

TABLE II
PDV VALUES FOR SMALL EXPRESS FRAME SIZES

Express flow #	72 bytes frame	132 bytes frame
1	19.59 us	9.44 us
2	6.15 us	9.44 us

This shows that using very small frame sizes requires extra care, because PDV can be higher than the serialization delay of a single frame and the intended order of arrival may be changed.

2) Assuming Imprecise Traffic Source Timing

We also investigated the effect of imprecise time synchronization in the network. We simulated this without BE traffic and with modified express frame sizes of 64 bytes on two topologies: cascaded and star (see Fig. 12) with the same arrangement as presented in Section IV.1.

Synchronization errors are modeled at the source by generating a Source Delay Variation (SDV) value. The SDV has a uniform distribution between 0 and maxSDV = 20 ns. This maxSDV value is large enough to cause changes in the order of arrival for express frames from neighboring sources. Note that preemption can protect express traffic against BE traffic only, thus, it will not help in this scenario. Time gating can avoid reordering, but it is also sensitive to synchronization errors. The result is that the PDV equals at least the serialization delay of one frame (6.72 us in this scenario).

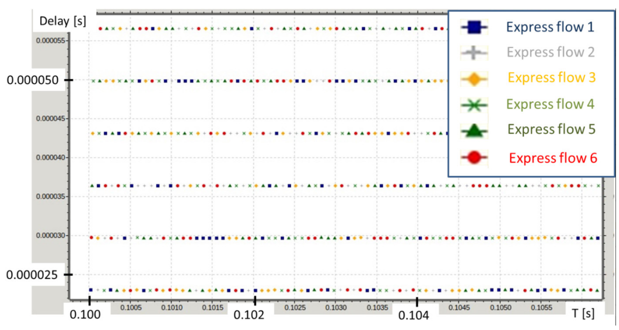

Fig. 12. End-to-end delays of express frames (star topology)

Note that PDV also depends on the topology. In case of star topology, in the worst case the affected express frame has to wait for one frame from every other flow, resulting in 5 times larger PDV than the PDV observed in the cascaded topology (see Table III).

TABLE III
PDV VALUES WITH SOURCE DELAY VARIATIONS (MAXSDV = 20 NS)

	Cascaded topology	Star topology
PDV	6.74 us	33.61 us

The conclusion is that the timing of the traffic sources should be designed or shaped by the first switch such that the relative frame arrival time measured at the output link, where they have the first interference, is larger than the maxSDV.

V. CONCLUSION

Due to promises of cheaper operation and converged networking there is much interest in the industry to replace Industrial Ethernet with standard Ethernet solutions. In this paper we have illustrated with simulations that standard Ethernet with TSN features can work as a replacement of Industrial Ethernet solutions. While in PROFINET (and generally in any Industrial Ethernet application) the control and scheduling of the traffic is part of the protocol, once we use standard Ethernet for transport there will be a split between the industrial applications and the transport network.

We have shown that while frame preemption protects the express traffic against the low priority traffic, the interference between express flows must be also resolved, as the total delay can include the serialization delay of other express frames in addition to the preemption delay. With proper time gated queuing configuration the PDV can be eliminated, because this realizes completely scheduled traffic in the network. Standard Ethernet allows using different link speeds in parts of the network, this can be exploited if link speeds are increasing towards the controller. We have also shown that both small and large frame sizes can induce worst case scenarios when using frame preemption.

Therefore, the design of the transport network, including the configuration of the TSN features requires special care. A possible way to handle these issues would be the introduction of a dedicated SDN controller that has an interface to learn the traffic details of the industrial applications.

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Novel concepts and devices in RFID based indoor localization using Smart Reader Networks and Intelligent Antennas

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***Abstract*—Industrial, logistic, and several other applications require the discovery, localization, and tracking of objects using existing passive radio frequency identification (RFID) based systems. We have analysed system concepts, methods, and protocols to enhance accuracy and coverage of RFID localization systems in order to find a moving transponder in an area with high precision over time using reading parameters and also to estimate the location of the transponder with low error rate if the reading information is not available. This research is also focusing on the infrastructure requirements of determining or recovering the location or path of the tag. The extension of the RFID localization beyond the area covered by the RFID reader system could be a solution. This can be carried out by using a special device called "Nodding antenna" or by supplying the transponders and antennas with the information on how to determine or store their respective positions. Advantages and application areas of the Location-on-Tag (LoT) concept and a novel localization method based on intelligent antennas that can enhance reliability and robustness of indoor RFID localization systems and ensure inter-building tag path tracking are introduced in this paper.**

***Index Terms*—Indoor localization, RFID, Intelligent antennas**

I. Introduction

RFID technology is the most prevalently used in identifying objects and the system is gaining more widespread use. This technology can be made viable for tracking objects in real-time and pinpointing their exact location. These solutions are not without difficulties because of radio frequency (RF) interference, and the sensitivity of the RFID tag affixed to the object, even the location of the reader can weaken the signal and its spread. Because of these reasons, determining the position of an object is one of the hardest and most fundamental problems.

Today, RFID-based localization systems are not very reliable therefore they cannot be used in several industrial environments or only with low efficiency. Our concept (LoT - see in section IV) to make it more precise is based on combining different solutions, such as smart algorithms developed for antennas, smart solutions implemented in tags (positioning, triangulation) and a mathematical model applied on the server side that enhances the measurement accuracy and the estimation of temporarily visible location transponders [[1]]. This algorithm performs likelihood probability calculations based on previously saved positions of the tags.

In addition, the transponders can store information that can be used to validate the location of tags estimated by the mathematical model in the following way: when a tag can be seen neither by the antenna nor the antenna connected to the cloud, its location will be estimated using its previous locations. If an antenna, that is not online, can see the tag it writes data into the tag. If an online antenna can see this tag, it reads off the positions of the tag, and sends them to the cloud immediately where the framework interprets them. This semantic information will be attached to the previously stored data and the framework can apply them. The results will be compared to the values estimated by the mathematical model. This method ensures more accurate measurement. These components, the algorithm of the antenna, the skill of the tag that can localize itself, and the mathematical framework, can be combined with the concept of LoT. After working out the model, a special smart tag has been prepared that can localize itself using the positions of the nearest antennas. (The system can also be used with standard RFID EPC C1 Ge2 transponders but they cannot localize themselves.) Besides, an intelligent antenna, the nodding antenna, a mathematical framework, and cloud based system have been developed. Smart tags, smart antennas and different frameworks existed previously[3], but our system combines them to increase accuracy. That is the reason why it is difficult to compare other systems.

The combination of existing and novel components and methods enhances the robustness and scalability of the system.

Our system employs fixed antennas to identify the tags affixed to the objects, however the method is also applicable in the case of mobile antennas. During our research we focused on three types of system architectures: A Smart Reader Network (SRN) where the reader antenna pairs connect to a network or server, fixing is done by the intelligent infrastructure, and the data describing the location of the object is created on the infrastructure side. A Smart Tag (ST) where intelligent and active RFID tags are used instead of traditional reader antenna pairs, fixing is done by the tag, and data describing the location of the object is created on the tag side, and a Hybrid System where the two approaches are

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combined.

Several algorithms have been integrated into the system in order to ensure the reliable localization of the objects in extended spatial and temporal domains. The next generation ”nodding” antenna prototype, and operational principles and the algorithms required for their operation and control are described in chapter IV.

Our goal was to find a solution to extend the detection process to permanently or temporarily uncovered areas by upgrading current RFID technologies and possibly by enhancing current RFID localization protocols.

In addition, we have examined how a new generation of RFID antennas and transponders may broaden the detection process. Therefore, RFID systems cannot only determine the presence of the transponder, but can also locate its position with higher accuracy.

The principle of operation of our antenna prototype, called a ”Nodding antenna”, and the potential of the developed novel intelligent control methods - with the suggested modifications of the protocols in order to extend the localization - are also described in this article.

Moreover, we also outline our plans on how we imagine the transmission and the storage of information required to determine the position of transponders, incorporating the Antenna Information Broadcasting (AIB) technology developed by Bánlaki, Hoffman, and Juhász [2]. The development of the novel antenna and the control algorithms are also presented in this article. They complement the localization with the transmission of information relation to the location of the transponders, and thus the system is capable of indoor localization without GPS based information (which is typically not available in indoor environments).

The system described in this article can be considered novel since it combines the RSSI-based distance measurement and direction detection [1] by using mathematical methods (likelihood functions[4]) and also implements new technologies, prototypes and models in the field of hardware development.

II. Related work

There are systems based on measuring the received signal strength indicator (hence, it will be referred to as RSSI), and also ones that accomplish either indoor localisation or introduce new models and different techniques. The most popular techniques are lateration, triangulation, statistical interference or simple Min-Max localization [6], [7], [8], [9].

The Multilateration is a simple range based decentralised algorithm [6], [9] based on geometric principles. This algorithm collects the beacons’ messages and estimates the distance between the nodes and the beacons. There are some range-based algorithms, such as the ROCRSSI [10] and the Min-max, and some range-free algorithms, for example the Maximum Likelihood (ML), that are based on classical statistical interference theory [11], [12]. There are a few published papers that combine a variety of techniques and apply them as a uniform system for localisation.

In order to localize an object, perception based localization can be used. It binds the position of the object and the infrastructure node while the object is close to the node. In most cases and applications this resolution is not sufficient.

Using only perceptional sensors and RFID based systems, it is relatively difficult to determine the position of an object accurately.[13] RFID can also be used as a perception based technology, and there are possibilities of expanding the perceptional capabilities of the mentioned devices (RFID readers, antennas, antenna networks, and transponders) with the implementation of intelligent algorithms.

Joho et al.[14] incorporated the signal strength into the sensor model to improve the mapping accuracy of RFID tags. Ran Liu et al.[15] used a 3D sensor model and a pair of antennas to estimate the 3D positions of the RFID tags. They installed two antennas at different heights on the robot to solve the ambiguity problem of heights estimation introduced by antennas placed at the same height. Germa et al.[16] combined RFID measurements with visual information to track people and other object using a mobile robot in a crowded environment. In their case, the RFID system was used to determine the direction of the object and its readings have to be fused with a vision algorithm to get a better estimation of the position. Deyle et al.[17] presented a solution that generated the RSS image of a tagged object for manipulation tasks of mobile robots. They constructed this image by rotating (for example panning and tilting) a mobile antenna and recorded the signal strength at the same time.

III. Location on Tag (LoT) concept

A Smart Reader Network can be extended with offline or temporally online Smart Readers that can only be manipulated with the tags using read and write operations. This alleviation allows the extension of the network to large areas without the need of infrastucture but temporally reduces accesibility to the location information. The concept of Location-on-Tag (LoT) enables storing and managing location information using offline readers until an online reader gathers the whole path.

Therefore, LoT means that the location information can be written into the memory of the given transponder by the reader-antenna pairs placed on the travel path of transponder. The method is as follows. Each pair along the path:

- reads the memory of the transponder containing the list of the previous locations,
- saves the list of the previous locations, and
- writes the current location information to the memory.

This is also possible in multiple phases which are a chance to write more than the status into the memory of the transponders. Accordingly, with every tag movement between different discrete locations that are covered by different antennas, the given antenna saves the previous positions and writes the current one into the tag memory. During this operation the antenna-reader pair sends the localization information to the edge server connected to the system, and stores the information about the position of the given transponder. This information is visible if we have security access.

Assuming that we have a set of reader-antenna pairs $RA = \{RA_1, .., RA_n\}$ and an RFID tag T, and a discrete time t_i

when the tag has appeared at the given antenna-reader pair RA_i.

RFID transponder memory can be organized as a circular buffer of location information. The buffer has a dedicated memory address that contains a pointer (BP) to the current location.

We can represent location information using a labelling function $L : RA \rightarrow P$, thus $L(RA_i) = L_i$. Here, P has a finite number of elements and $P \subset \mathbb{N}^+$. The size of a position element (S_T) in bytes can be calculated as follows.

$$S_P = \lceil \frac{\log_2 |P|}{8} \rceil = \lceil \frac{\log_2 n}{8} \rceil \quad (1)$$

If the size of the given tag T memory in bytes is S_T, the maximum number of the positions that the tag can store in the list is

$$c = \lfloor \frac{S_T}{S_P} \rfloor \quad (2)$$

.

If we take into account the size of the buffer pointer S_{BP}, we can calculate the corrected number of elements c' in the buffer.

$$S_{BP} = \lceil \frac{\log_2 c}{8} \rceil \quad (3)$$

$$c' = c - S_{BP} \quad (4)$$

The implementation of the extended commands for localization can be performed by RFID read/write commands.

- $READC(t) : c'$: reads capacity c' of tag t according to (3) and (4)
- $READBP(t) : BP$: Reads BP of tag t
- $READPOS(t, BP, i) : L$: Reads i-th position from BP of tag t, $i \in \{1..c'\}$.
- $WRITEPOS(t, BP, L)$: Writes the current antenna label L to position BP in the memory of tag t.
- $INCBP(t)$ Increments BP of tag t according to (**??**).

According to the above commands, the following algorithm can be used to locate tags in the area covered by connected antenna A.

We can also execute $SMART\_FIND(A)$ procedure for all connected antenna.

By using LoT, the system can follow and draw the path of the given transponder. This feature is very useful to solve some indoor localization problems.

In addition to indoor usage, the Smart Reader infrastructure is also suitable for inter-building localization if the reader-antenna pairs are deployed in separate buildings.

Since location data is stored in a circular buffer and the current position is pointed to a buffer pointer (BP) that is also kept in the memory, a data consistency is an important problem to solve. Especially, when the tag moves outside the antenna range, the operations ($READC$, $READBP$, $READPOS$, $WRITEPOS$, $INCBP$) can be interrupted at any time.

If Algorithm 1 is interrupted before $WRITEPOS$, no integrity error will occur. But if the method is interrupted after $WRITEPOS$ is performed successfully, then the buffer pointer BP will turn invalid. The next reader RA_k along the tag path will find the RA_i as the last position in the list.

```
LRA := L(RA)
T:=FINDTAGS(A)
for all valid tag t in T do
  c':=READC(t)
  if c' > 0 then
    LIST:=∅
    BP := READBP(t)
    i:=0;
    while i ≤ c' do
      L:=READPOS(t, BP, i)
      LIST := LIST ⋃{L}
    end while
    Send record (LRA, t, LIST, TimeStamp) to server
    LIST := ∅
    WRITEPOS(t, BP, LRA)
    INCBP(t)
  end if
end for
```

Algorithm 1: $SMART\_FIND(A)$

RFID UHF C1G2 protocol does not contain basic command to write to a memory starting from more than one memory addresses. Thus, we suggest introducing commands $AWRITE$ and $COMMIT$ that can be defined as follows:

- $AWRITE(T, A, D, L)$, where T is the tag, A is the write address, D is the data, and L is the write length. This command writes data to a buffer at tag side and data is not written into the memory until $COMMIT$ is executed.
- $COMMIT(T)$, where T is the tag. This command copies data of all finished $AWRITE$ commands.

To ensure privacy, reader authentication must be used and/or location information must be encrypted before it is written to the tag memory.

RFID has limited encryption and authentication capabilities due to the power consumption of these methods (we should consider a passive tag).

Data can be protected by only allowing authenticated readers to access the location buffer in the memory of the tag. UHF RFID protocols offer passwords (access codes) and custom commands for accessing tag memory and protecting it from unwanted reads and/or writes. Our goal is to find methods for more structured and also more sophisticated reader authentication using current RFID commands or make proposals to extend the protocol.

Data can also be protected by encryption, but due to the limited capabilities it is better if the Smart Reader infrastructure performs the encryption rather than the tag. Except BP, data can be encrypted by method E using a secret key K that can be individual for reader-antenna pairs:

$$C_{RA_i} = E(K, L_{RA_i}) \quad (5)$$

Unfortunately, C_{RA_i} only depends on RA; thus, if one can read encrypted location once (e.g. by putting a fake tag T' to the area covered by RA_i reader-antenna pair) then one can easily track tag T along its path without knowing K.

To eliminate this, we suggest encrypting data using the ID of the tag T too.

$$C_{RA_i,ID_T} = E(K, L_{RA_i}, ID_T) \tag{6}$$

Consequently, decryption can be done using D.

$$L_{RA_i} = D(K, C_{RA_i}, ID_T) \tag{7}$$

Alternatively, an RSA based method can be used to encrypt location data on the tag. Smart Readers can generate a public key PK_T and secret key SK_T for tag T. Using them, the reader can encrypt data using tag PK_T and write it to the tag. Smart Readers can send SK_T to the server to ensure decryption. To ensure encrypted write operations, readers have to know the public key of tag T, thus, PK_T must be written to the tag memory.

According to the encryption schemes above, although one can read encrypted data C_{RA_i,ID_T} and tag ID ID_T or public key PK_T, it is hard to find L_{RA_i} without knowing K or PK_T.

IV. Intelligent antennas

In order to conduct indoor localization, a certain type of intelligent antenna is applied that can change the antenna characteristics by determining the current location of the transponders and using three integrated patch antennas. The antenna is able to discover the transponders at a given location by turning to the appropriate direction (without mechanical movement).

The goal was to expand the localization in order to be able to determine the status of a given transponder, even in such areas that are hard to cover, and if we manage to detect it we will also be able to follow its movement.

Our expectations regarding the antenna were the following: It should not require external power supply, and it's working range of frequencies should be between 865-868 MHz. It must be made in accordance with the ISO 18000 and the EU standards, and it should be able to form at least five different kinds of characteristics in the given output. This is the most important feature of the antenna. This is the device that we use to make the indoor localization more accurate.

The reading range is mostly identical to the local antennas (typically 6-8 dBi), which is also important because of the working standards.

Control of RF signals can be completed by using the GPIO (general-purpose input/output) output of the RFID reader. Control could also be completed via Ethernet connection, but this would mean bringing new protocols into the system, which would further complicate its operation. The overall size should not go above 60 * 60 * 5 cm.

Employing the possibilities extended by the three antennas, the control unit is able to turn its characteristics into three discrete directions. (Electricaly adjustable characteristics.) The controlling electronics accomplish switching between the antennas by addressing the GPIO port located on the reader.

This solution is efficient with three antennas, however, in our case, the set of antennas needs to see in five directions instead of two, which implies that the GPIO port, in its current form, is insufficient to be used as a control unit.

Thus, a new method and device were deployed for switching any number of antennas part. A TP Link has been changed that requires a separate power source but it allows the antenna to be switched through the Internet and does not require manual switching. A virtual switch has been built in the TP link device that can control the antenna directly and get commands by means of standard TCP/IP based communication. The reader linked to the antenna can not perceive this but passes the measured values to the system. As the system sends the command to the antenna orientation, it knows which antenna characteristic received measured value belong to which antenna characteristic. It also knows the relative positions of the given transponders compared to the position of the antenna. This information is stored in the cloud and it is required in the memory of the transponder. Thus a special, dual control is obtained.

We have also designed and developed the software that can control the antennas in a way to be able to store the data collected from the transponders. It can control the special antenna set intelligently and manage to carry out the information spreading orders, which is described in the chapter III.

The Nodding antenna prototype can be turned in two or possibly three directions which is not adequate in all cases. Thus, we decided on the development of a variant of the antenna prototype that is capable of six different orientations. For this purpose, the number of integrated patch antennas were increased to six. With this solution the efficiency of indoor localization can be greatly improved.

Beside the above benefits, we found problems that led us to be able to discover new possibilities and results.

The first one is the control of the antenna. As the antenna uses six separate patch antennas (see in [1]), control of the GPIO port is insufficient to produce different antenna characteristics, because it can only generate low and high signals. This solution is adequate in the case of three patch antennas but with a set consisting of six antennas it becomes inoperable. Thus, the control of the antenna can be done by using an additional tool, namely a modified TPLink type device. This means that the power state of the pairs and triplets of patch antennas that produce different directions is controlled via an Ethernet link and UDP protocol. This controls the antenna on a higher level of abstraction that makes the reading of data and software control easier and more scalable.

The other problem that needed to be solved that the earlier control of the characteristics of the antenna resulted the coverage of separated space segments. For the new antenna, these space segments become overlapped.

In practice, this means that turning the characteristics of the antenna left in the right side space segment we do not receive a signal of 0 dBm strength but some easily measured strength from the the transponder.

This makes the operation of previously used algorithms impossible, but considering the problem it is clear that this attribute would prove to be useful during the measurement of localization information.

The previous antenna, which could be turned in two directions did not use output power information, therefore it can solely provide the information whether the transponder is readable or not. If yes, then the transponder can be considered to be in the space segment where the antenna is directed to.

Using the antenna that scans in multiple overlapping directions we can measure the strength of the signal scattered by the transponders in the space segment with patch antenna pairs.

As every pair can see it with different strengths and the measurements are not simultaneously performed, the position of the fixed transponder can be determined with significantly better precision from the received signals.

While in the first case only the two sides could be differentiated now not only can we differentiate six directions but can even determine the possible location of the transponder within these space segments using the signal strength. At present we are using this type of the antenna prototype to make measurments.

The measurement results of the model and the prototype have supported our assumptions, that its localization ability.

With the contractor produced the prototype we have performed measurements jointly to confirm our thesis.

The frequency range of the antenna is 865 - 868 MHz, the input reflection for the whole band is larger than 13 dB, and the gain is 6 - 8 dBi. Six different characteristics can be configured that cover separate space segments. Its dimensions are 510x360x50 cm. The power controller is made using an RJ45 (ethernet) connector with POE.

The structure of the main beamer is made of a left and right half-circle which means that we have left and right coiled antenna type. The types can be used together, however, better results can be achieved if a standard RFID antenna is used since the transmitter and a nodding antenna are used as the receiver.

Figure 2 represents the block diagram of the antenna. On the left side, the patch antennas can be found and the numbering represent their positions in the matrix. For example, patch11 PCB (Simple Printed Circuit Board, the structure of the PCB is not important in this paper.) is the first antenna in the first row. An itegrated patch antenna can be controled by the system software. As it can be seen in Figure 2, one antenna and one controller make up a unit, called patch antenna. On the right side, the controller of the antennas (antenna control unit) can be seen. One patch antenna can be controlled through a standard RJ45 (at present instead of GPIO), Ethernet (PoE) connection by the antenna software (12..48V DC voltage). The functions have been added to the system by changing the TPLink device that also redeems the control of the GPIO antenna.

The antenna with the switching of phases can select exactly six spatial angles.

Because of limitations due to size (the usability of antenna requires them), maximally a patch antenna grid of 3x2 cells can be established on the surface of the antenna. These are situated in a single plane and face forward in a single direction (see in Figure 1).

The setup of the antenna beam with controllable phase shifters with a given possible amplitude distribution results

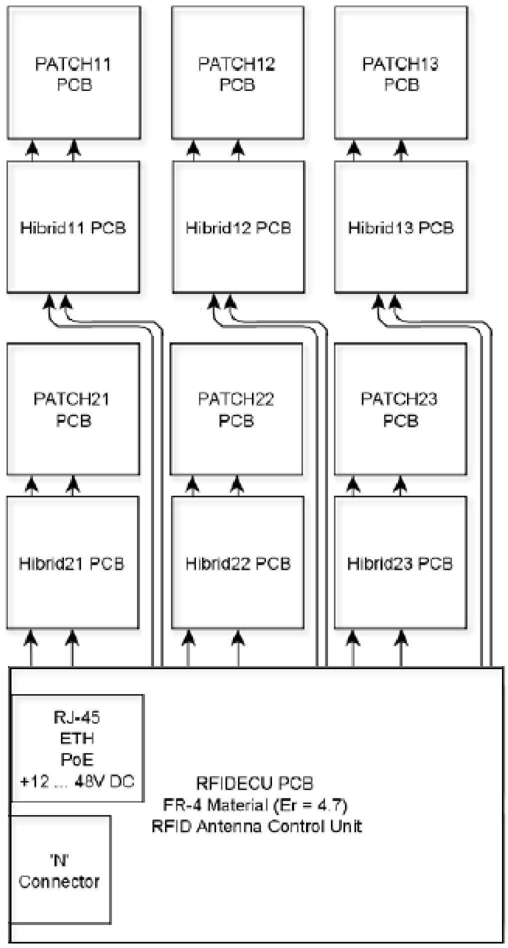

Fig. 1. Integrated patch antenna set

in the following directions:

- Beam looking at $-30°$, with distance of 210, 150, illuminance of 0,5 - 1, 0,75, and phase of 180, 270, 40, see in figure 2.
- Beam looking at $0°$, with distance of 210, 150, illuminance of 0,5 - 1, 0,75, and phasee of 180, 270, 40, see in figure 3.
- Vertical beam looking at $0°$ - with distance of 210, 150, illuminance of 0,5 - 1, 0,75, and phase of 180, 270, 40.
- Beam looking at $30°$ - with distance of 210, 150, illuminance of 0,5 - 1, 0,75, phase of 180, 90, 30.
- Beam looking at $15°$ - with distance of 210.150, illuminance of 0,5 - 1, 0,75, phase of 180, 270, 40.
- Switching on all patch antennas of the antenna system produces behaviour similar to standard RFID antennas.

If we consider an intelligent antenna control logic which can set antenna characteristics to d different directions $\{A_0, .., A_{d-1}\}$, the control logic can switch them using the round-robin method. The switching logic can be implemented using the following formula:

$$A_{current} := A_{((current+1)(\mod d))} \tag{8}$$

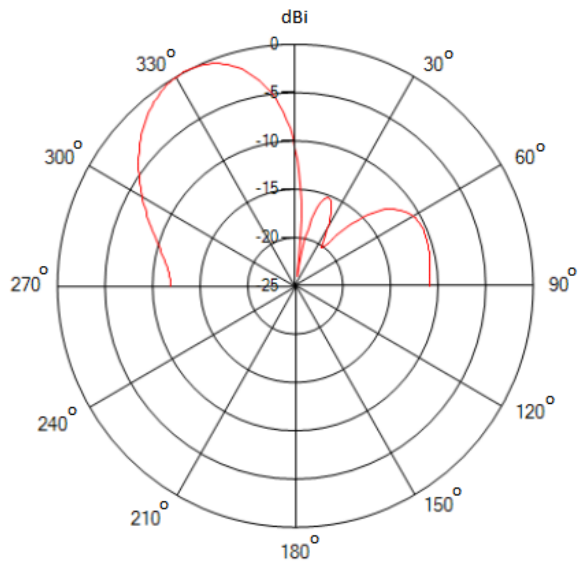

Fig. 2. Beam looking at $-30°$. The red curve represents the covered area. (Measured values.)

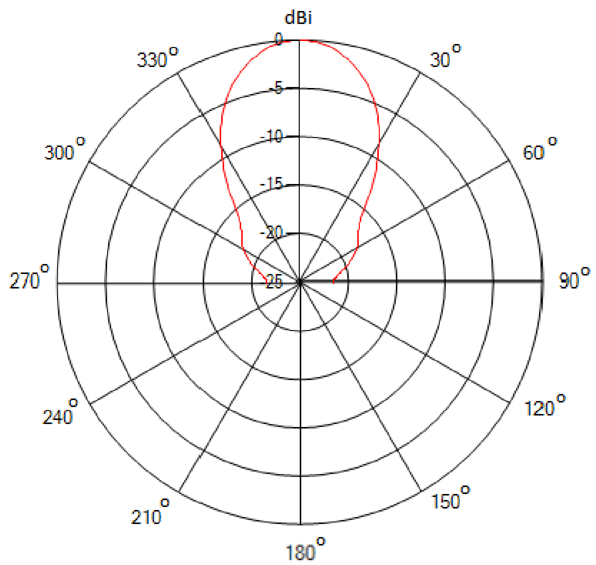

Fig. 3. Beam looking at $0°$. The red curve represents the covered area. (Measured values.)

It is possible to extend our LoT command set with commands for intelligent antennas. These can be implemented using basic antenna commands.

- $NODDING(A)$: *bool*: TRUE if A is a Nodding antenna.
- $ANTINIT(A)$: d: Initializes the controller logic of Nodding antenna A and sets direction to A_0. Returns the number of directions d.
- $ANTLOOK(A, d_i)$: Changes the antenna characteristics of Nodding antenna A to i ("look at i-th direction");
- $ANTNEXT(A)$: d_i: Sets the next direction of Nodding antenna A and returns with its number d_i.

$d := ANTINIT(A)$
$d_i := 0$
while $d_i \leq d$ **do**
  LRA := $L(RA_{d_i})$
  T:=$FINDTAGS(A)$
  for all valid tag t in T **do**
    c':=$READC(t)$
    if $c' > 0$ **then**
      LIST:=$\emptyset$
      BP := $READBP(t)$
      $i := 0$
      while $i \leq c'$ **do**
        L:=$READPOS(t, BP, i)$
        LIST := $LIST \bigcup \{L\}$
      end while
      Send (LRA,t,LIST, TimeStamp) to server
      LIST := $\emptyset$
      $WRITEPOS(t, BP, LRA)$
      $INCBP(t)$
    end if
  end for
  $d_i = d_i + 1$
  $ANTLOOK(A, d_i)$
end while

Algorithm 2: $SMART\_FIND\_NODDING(A)$

According to the above commands and the $SMART\_FIND\_NODDING(A)$ procedure, cyclic reading can be used for localization with both Nodding and normal antennas.

The antenna broadcasts in the following ways. First, it performs a detection check in all possible area sections that the patch antennas can separate from each other (one-by-one, in order), which means that it detects the transponders that are currently there, and it stores their identifiers with the help of the control software. In the next step, if there is previous information in the transponder, it saves it in a different memory block of the tag memory and writes the current position of the detected devices into their memories. It repeats this procedure in all possible area sections and then restarts with the first one after the configured synchronisation time has been reached.

In the case of detecting a tag with more then one antennas, there are three options (naturally, in the order they are written down):

- we attempt to determine its location from the information that was previously written to the transponder,
- we decide which discrete area section the transponder is currently from the the calibration data of the given location and measuring the received signal strength (RSS),
- if the transponder is a Smart Tag its information will be read.

- if neither can be done, then it is possible to determine the most likely location of the transponder we are looking for with our mathematical subsystem.
  The subsystem should be able to calculate the coordinates of the transponder (or maybe even a moving reader in the future), that is fixed in the system. These calculations are based on the previously stored detections (see in [1], [4]). The subsystem attached to the localization framework is not able to perform the localization alone but can be used to estimate the location of the given transponder in the case of either receiving uncertain information or undetectable space parts. We are currently working on developing the subsystem based on mathematical foundations and according to our results this kind of localization method can be used as an independent subsystem.

It was necessary to know, whether the data written on the transponder by the previous antenna must be stored or it is needed to make it possible to set the value of this data in the given system (SET). By using this algorithm, it is definable which area section the transponder comes from and what its current location is.

In this case, the antenna informs the transponder about its own location, and through it, to the other readers or a nodding antenna records where the transponders are located in the given space.

Both solutions can be used for the extension of the RFID based identification. In the first scenario, a predefined number of transponders (5 tags/cell) can be placed in a closed area where the readers and the antennas are fixed and configured on every important control point. The antennas spread their current status onto the transponders by broadcasting, transmitting the information needed for every other reader that wishes to gather data for indoor localization as well.

In the area that is covered this way, we can even use a simple handheld reader to gather information about the status of every transponder all along the way, which can then be processed by the navigation software that is integrated into the reader, and we can navigate the user of the system to the appropriate direction. During our research, we have also developed navigation software and it worked according to our expectations. (In this phase of the research, the information required for determining current status was written to the transponders, used for navigation, manually by using an another handheld reader before putting out information but considering the proof of theorem it is irrelevant.)

In the second case, we can monitor the status and the movement of each device equipped with a transponder and this movement can even be presented in a graphical display (we have software development project in this field).

There is a third aspect that is connected to the social acceptance of RFID. In the described situation, the transponder contains information about its path so that it can only be read by readers that have permission.

This option could be influenced by the small memory capacity of the transponders, but if we write all the positions of the path using a few bits for encoding, we can track their movements in a relatively large area. If we place reference points along the path, that save and store information that belong to the transponders, whose memories are almost full, in database in the edge server of the system and assign an identifier and an authentication code (with password), the memory of the tag can be deleted so it is suitable to travel further on the path without a third party having access to this information. The user who owns the transponder can permit or prohibit the reading of the location information.

In contrast, in our model the RSSI value is not the most important factor. In addition to the measurements, the space can be separated by changing characteristics of the antennas that allow the determination of the position of the transponder relative to the position of the antenna. The resolution depends on the quality and quantity of antennas. On the other hand, the previous positions of transponders are stored in them so it can be followed and used as additional data for the analytic system that is connected to the antenna.

V. Localization framework

The methods developed and presented can be combined effectively for the purpose of implementing RFID-based localisation efforts.

To enhance the possibility of finding the location of the tag, the methods can be integrated into one system. In the case of the Smart Reader localization method using LoT, the locations (path) are in the tag memory, thus, Smart Readers can recover the entrie path when the tag enters to the Online Readers area.

If it is known that the tag is in the area but it cannot be read for a while (e.g. because it is temporary in an uncovered area), its position can be still estimated using the mathematical framework. Using these methods, location can be determined or estimated in all cases and at all discrete times. This combination of localization methods is suitable for various indoor and outdoor localization tasks.

An algorithm that performs likelihood probability calculations based on the previously saved positions supports the system. This estimates the current position of the tag in case it cannot be seen temporarily or it has disappeared. It is also able to complement the path with estimates when the tag cannot be temporarily seen.

Three data sources are available for finding the position of the tag: data measured by the tag, data measured by the nodding antenna and the mathematical subsystem. From these three data sources, it is possible to pinpoint the position of tag even in extreme circumstances, for example high shading or poor coverage. The system can cover huge areas such as airports or train stations.

We use antenna side RSSI measurement based detection, self-localisation in the tag-side, as well as novel mathematical techniques to support the localization [1]. This article analyses the entire system components of the Smart Reader Network.

The localization framework is presented in figure 4.

The principle of the developed framework is as follows: the system divides the space into six parts in two dimensions with the help of the the nodding antenna. The transponder is detected in each of the obtained subspaces but at different strengths, thus the location can be determined.

Since this resolution is not sufficient, the location of the transponder can be determined approximately in a subspace by

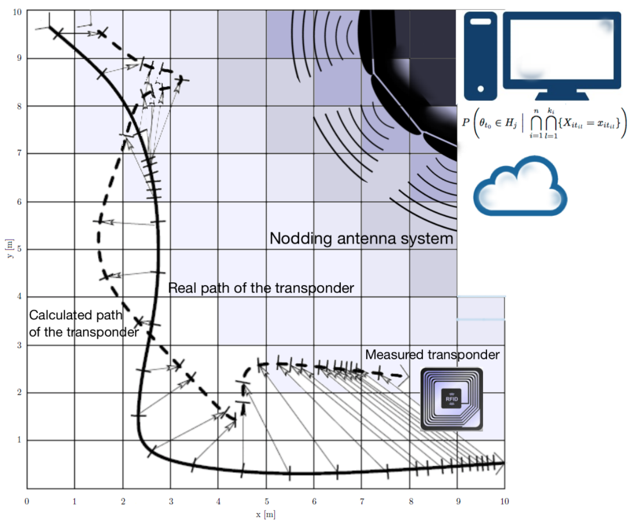

Fig. 4. The system architecture. (One grid covers 1 m^2 area in real life.)

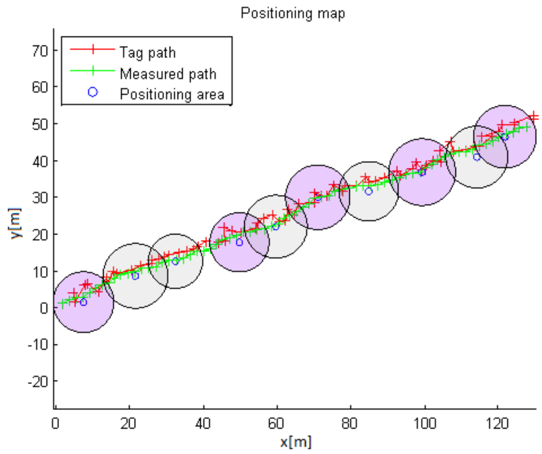

Fig. 5. Localization map with path(green), measured positions(red) and positioning areas: online (purple circles) and offline(grey circles)

using both the calculations of the mathematical subsystem [1], [4] and the previously measured positions of the transponder that are stored in the cloud. The location of the transponders can be estimated by the stored data and the mathematical calculations even if the transponder is temporarily not seen by the antennas and readers. The algorithms applied to complete the mentioned functions are discussed in this article. The tag-side (ST) localisation will be published in our next article.

VI. RESULTS

The error of a localization system can be defined as the (Eucledian) distance between the current position and the estimated position of a given object (or an RFID tag in this case). The error of the RFID localization system varies over time. Between measurements, when a tag is not visible for any online readers, only an estimate of the position can be given. The precision of this estimated position strongly decreases over time. In the case of the LoT concept, the offline smart readers can locate the tags and the next online reader can reestimate the position using the location and time information stored in the tag memory. Thus, the LoT concept enhances scalability and reduces localization error in RFID systems.

We analyzed how can LoT method increase localization accuracy in a positioning system using simulation. As can seen on Figure 5 we assumed online (purple) and offline (grey) localization areas with along the path moving transponder. A localization accuracy for a system with positive deviation ($\sigma_p > 0$) is used. Path (green) is generated by a random walk on the positioning map and localization error using Gaussian with $\sigma_p > 0$ is added (red). The tag is only measurable in any (online or offline) localization area.

The positioning error can be defined as a function of the time. In time t, the squered norm of the difference of actually (in time t) known position ($m(s,t)$) of time $0 \le s \le t$ and the position $m(t)$ in the same time:

$$E(t) = \sum_{s=0}^{t} \|m(s,t) - p(s)\|^2 \qquad (9)$$

Using values above, localization error of the systems with and without using LoT method was calculated. We simulated 40 points in a path and generated 10 localization areas using k-means clustering of path points (Figure 5). The areas are divided to online (purple) and offline (grey) area groups.

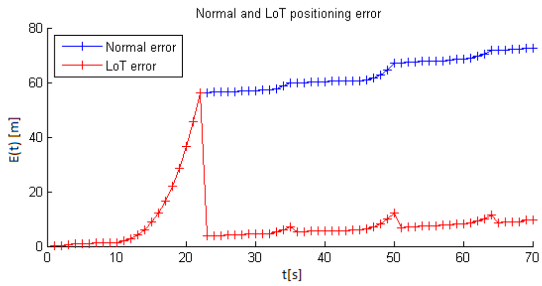

Fig. 6. Localization results with and without LoT method

$E(t)$ is calculated over time and the results can be seen in Figure 6. This means that the total error is reduced by 5.7 times with LoT method.

The accuracy of the localization is affected by other tags nearby, thus, a minimum distance of 20 cm is selected empirically. However, this criterion solves the field drain problem, the read time increases with the number of the tags. We did not focus on large tag numbers in this research, therefore measurements is are done with a maximum density of five tags per localization area.

A novel antenna type has been implemented in order to improve the reliability of the localization procedure and provide extended information on the transponders detected by the antenna that not only determines the status of the transponder in the surveyed area, but also gives information to the transponder (LoT concept).

This process provides an opportunity for us to determine the status of a transponder assuming that the developed control software of the reader writes the identifier of the given sector of the area onto the transponder (using LoT method) for each case of an area covered by changing characteristics. If the antenna notices the same transponder at another location at a different time, it places the previous area section identifier to another memory address then writes the current identification into the memory as well.

These are complemented by the localization system operating on a mathematical foundation [1] that can pinpoint the exact location of objects using the measured and stored positions and RSSI (Received Signal Strength Indicator) values unlike previously known models.

The system can calculate the actual position of the given transponder when the transponder is temporarily covered by something. This calculation is based on the previously stored detections. Figure 4 shows the valid and the measured route of an experimental transponder detected by the system. The route 1 (continous curve) and a characteristics estimation (dotted line). The current and estimated positions at the same moment are connected by arrows. The squared error for the estimation is commonly 5.8 cm (see more in [1]).

As a solution for the aforementioned expectations, a webservice has been implemented in Java programming language observing REST (Representational State Transfer) principles. The chosen service application sever was JBoss, since it readily supports the creation of RESTful APIs.

The permanent storage of the detection items is completed inside a database, in our case, this is a PostgreSQL database. Communication between the database and the server is accompolished by the help of an ORM (Object/Relational Mapping). Our choice for an ORM tool fell upon Hibernate.

The implemented version can select the object that is most likely to be localized from the temporarily or permanently uncovered discreet areas.

VII. CONCLUSION

Indoor dynamic positioning problem in RFID systems was presented and current application challanges was described. Current methods and systems for enhancing positioning accuracy of dynamic RFID systems was analyzed.

Novel methods was introduced including Location on Tag concept to reduce positioning error over time by writing known positions to the tag memory along its path. Novel methods for ensuring data security of RFID localization systems was presented.

A novel 'Noddling Antenna' was designed to extend area of coverage and find tags in a more sophisticated way. A Smart Reader Network based positioning method was introduced where the network consists of online and offilne intelligent antennas running a noddling method and Location on Tag readings. A likelihood probability based framework was used to estimate tag positions based on previously saved positions when tag reading cannot be done. A combination of RSSI measurements, the Smart Reader Network framework and the position estimator framework was presented.

Concepts and methods are analyzed using simulations and measurements. Promising results was seen in the RFID positioning scenario. It was found that the novel methods reduce position estimation error over time while increase the precision and the amount of information availiable for a moving RFID tag in a given time.

In the future, by making antennas, transponders, frameworks, and developing more intelligent protocols, as well by employing middleware that applies the novel tools, the RFID technology could be made capable of locating objects more accurately. As a result, many new - currently unknown - applications hopefully will be developed by the RFID technology.

During our research, we paid close attention to both the examination of the dynamic modifying possibilities of the characteristics of the antenna and creating algorithms that can most precisely determine the location of certain objects by the readings of the intelligent antennas that redundantly cover the area. As a side result of our research, it is necessary to make a suggestion regarding to the extension of the EPCGlobal RM (Reader Management) standards, where the localizing ability appears at the level of the Read Point (antenna) instead of the level of the Reader Device (interogator).

By dynamically changing the characteristics of the antennas, we would like to work out a general model in line with upgrading of the hardware and software which results in the commonly used global positioning that could be performed in an indoor environment.

Smart Tag (ST) RFID localization architecture is the inside out version of the SRN solution above. To be able to enhance reliability and precision of localization, our mission is to develop a new type of Smart Tag and a hybrid localization system. This combination could keep the advantages both SRN,ST and the mathematical based localization systems. The tag-side (ST) localisation will be published in our next article.

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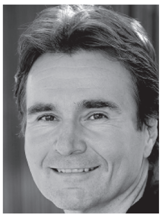

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Track 1: PHY and Fundamentals

- Channel modeling, characterization and estimation
- Modulation, coding, diversity, equalization, synchronization
- OFDM, multi-carrier modulation, waveform design
- Interference modeling, management, cancellation and alignment
- PHY strategies for low-rate, sporadic and asynchronous communications
- MIMO, massive MIMO and cloud-RAN
- Cooperative, device-to-device and multi-hop communication
- Cognitive radio, spectrum sensing
- Content caching and storage in wireless networks
- PHY layer design for cellular, wireless LAN, ad hoc and sensor networks
- Energy efficient and energy harvesting PHY layer design
- Joint information and energy transmission
- PHY layer security and privacy, ultra-wideband, mmWave and sub-THz communication
- Information-theoretic aspects of wireless communications
- Signal processing for wireless communications
- Molecular and nano communications

Track 2: MAC and Cross-Layer Design

- Wireless MAC protocols for 5G: design, analysis, and optimization
- Cognitive and cooperative MAC
- MAC for mesh, ad hoc, relay and sensor networks
- Scheduling and radio resource management
- Cross-layer MAC design
- Software defined radio, RFID MAC
- QoS support and energy efficient MAC
- MAC protocol for energy harvesting wireless networks
- MAC design for multitier cellular/small cell networks
- Multiple access in machine-to-machine communication
- MAC for cloud-RAN
- MAC protocols for molecular and nano networks
- MAC protocols for mmWave networks
- Full-duplex MAC design
- Cross-layer design for massive MIMO and multiuser MIMO networks

Track 3: Wireless Networks

- Software-defined mobile/wireless networks
- Wireless Network Functions Virtualization
- Virtual network management and orchestration
- Mobile cloud
- Fog computing and networking
- Mobile Edge Computing
- Mesh, relay, sensor and ad hoc networks
- Routing in wireless networks
- Cognitive radio and networking
- Resource management and optimization
- Big Data enabled Self-Organized Networking
- Mobile big data and network data analytics
- Integrated Wireless/Optical networks
- Mobility, location, and handoff management
- Multimedia QoS and traffic management
- Wireless broadcast, multicast and streaming
- Congestion and admission control
- Wireless network security and privacy
- Mobile social networks
- Wireless network measurements and characterization

Track 4: Emerging Technologies, Architectures and Services

- Mobile/Wireless network support for vertical industries
- Adaptive content distribution in on-demand services
- Context and location-aware wireless services and applications
- User-centric networks and adaptive services
- Wireless body area networks and e-health services
- Intelligent transportation systems
- Dynamic sensor networks for urban applications
- Wireless emergency and security systems
- Ultra-reliable communication
- Enabling regulations, standards, spectrum management
- Hybrid licensed/unlicensed spectrum access schemes (e. g. licensed-assisted access)
- Technologies, architectures and enabling business models for rural communications
- Satellite-based mobile access and backhaul
- Hybrid satellite-terrestrial networks
- Full duplexing
- Joint access and backhaul schemes
- Testbed and prototype implementation of wireless services

CALL FOR TUTORIALS AND WORKSHOPS

Proposals for tutorials and workshops are solicited on hot topics for future wireless communications systems and applications.

CALL FOR PANELS

Panel proposals are also solicited on technical, business and policy-related issues and opportunities for the wireless communications industry.

Accepted and presented papers will be published in the IEEE WCNC 2018 Conference Proceedings.

IMPORTANT DATES

Paper Submission Deadline:	September 15, 2017
Notification of Acceptance:	December 15, 2017
Camera-Ready Submission:	January 12, 2018
Tutorial Proposals:	September 15, 2017
Workshop Proposals:	Separate Call-for-Proposals
Panel Proposals:	September 15, 2017

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ENERGYCON 2018

IEEE International Energy Conference

Call for Papers

Towards Self-healing, Resilient and Green Electric Power and Energy Systems
June 3-7, 2018

Aim & Scope

ENERGYCON 2018 is the 5th IEEE International Energy Conference and will be held between 3-7 June 2018. It is organized by the IEEE Cyprus Section, the IEEE PES Cyprus Chapter, and the KIOS Research and Innovation Center of Excellence of the University of Cyprus, in partnership with IEEE Region 8.

ENERGYCON covers a broad range of electric power and energy systems topics and is open to contributions that are related to the theme "Towards Self-healing, Resilient and Green Electric Power and Energy Systems".

ENERGYCON aims to attract scientists, professional engineers and engineering students from all over the world and give them the opportunity to present and publish their work, discuss, exchange ideas and knowledge as well as network for future collaborations.

Accepted and presented papers will be published in the conference proceedings and appear in the IEEE Xplore Digital Library.

We are looking forward to organizing an exciting and memorable conference with a rich technical and social program. The conference venue will be the St. Raphael Resort, which is a 5-star hotel located on one of the most renowned and largest beaches in Limassol, 10 minutes away from the lively center of the city.

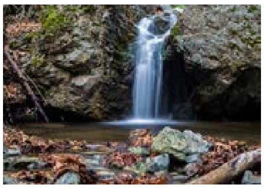
Topics

Papers are invited on all topics related to electric power and energy systems, and especially with the following focus:

Modern Transmission Systems
- Wide Area Monitoring, Protection, and Control
- HVDC Transmission Systems
- Transmission System Planning
- FACTS

Active Distribution Networks
- Monitoring of Distribution Networks
- Integration of Distributed Energy Sources
- Active Management of Distribution Systems
- Optimal Planning of Distribution Networks
- Microgrids
- Protection of Distribution Networks






Energy Storage and Renewable Energy Systems

- Integration of Energy Storage Solutions to the Grid and Their Impact
- Connection of Offshore Renewables to the Grid and their Challenges
- Modelling of Renewable Energy Sources and Storage Technologies
- Intelligent Control of Renewable Energy Sources
- Forecasting Applications for Wind and PV Generation
- New Ancillary Services Supported by Energy Storage and RES

Electrification of Transportation Systems

- Energy Management of Transportation Systems
- Electric Vehicles as a Mobile Energy Storage
- Batteries for Electric Means of Transportation

Hydrocarbons and Environmental Applications

- Natural Gas and Power Market
- Environmentally Friendly Solutions for Power Generation
- Energy Efficient Buildings
- Integration of Low Carbon Technologies

Information and Communication Technologies in Power Systems

- Smart Cities
- Communication Network Architectures and Protocols for Smart Grids
- Big Data Analytics in Power Systems
- Modern Control Centers
- Technologies for More Secure and Reliable Power System Operation
- Interdependencies Between Power System and Communication Network

Energy Conversion

- Power Electronic Technologies
- Electric Machines
- High Efficiency Electrical Machines and Drives for Energy Saving
- Fuel Cells

Cyber and Physical Security

- Cyber Security of Smart Grids
- Physical Security of Power Systems from Terrorist Attacks
- Requirements and Standards for Cyber and Physical Security in Electric Systems
- Power System Resiliency to Cyber and Physical Attacks

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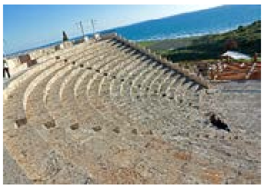
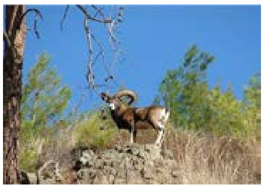
Important Dates

Paper Submission: 15 October 2017
Tutorials/Special Sessions proposals: 1 October 2017
Notification of Acceptance: 15 February 2018
Camera-Ready Papers: 01 April 2018



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,
"Template and Instructions on How to Create Your Paper".

Length of the manuscripts

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 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
c) Title of periodical in full and set in italics
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.

All references should be referred by the corresponding numbers in the text.

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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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SCIENTIFIC ASSOCIATION FOR INFOCOMMUNICATIONS

Who we are

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 1000 individual members, the Scientific Association for Infocommunications (in Hungarian: Hírközlési 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.

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.

To achieve these goals, we…

- 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;
- follow the national and international trends and results related to our field of competence, foster the professional and business relations between foreign and Hungarian companies and institutes;
- 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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