

# Low-Complexity Wireless Communication Modeling for Information Flow Control in Sensor Networks

E. van Foeken

TNO Technical Sciences  
Den Haag, Netherlands  
University of Amsterdam  
Amsterdam, Netherlands  
[eelke.vanfoeken@tno.nl](mailto:eelke.vanfoeken@tno.nl)

M.R.J.A.E. Kwakkernaat

TNO Technical Sciences  
Helmond, Netherlands  
[maurice.kwakkernaat@tno.nl](mailto:maurice.kwakkernaat@tno.nl)

*Abstract - The increasing demand for shared awareness in multi-platform sensor systems requires advanced wireless information sharing techniques. The analysis of these techniques requires information about communication resources and latency to be available in models. The work presented here introduces generic low complexity models that describe the probability of latency and the required resources in terms of communication costs. The models are meant to be used in highly realistic simulation scenarios. Therefore and for making them generic for a broad spectrum of scenarios the models are made as simple as possible. Nonetheless, they maintain the most important features of communication techniques. The models are meant to estimate the dynamic communication situation. Subsequently resource management can be used for more efficient and effective communication. The results show that real-time estimation enables grounded decision-making about whom to communicate with and that resource management enables changing the probability of delay and cost of communication.*

**Keywords:** Shared Awareness, Multi-Platform Sensor Systems, Communication Constraints, Communication Model, Information Value, Wimax.

## 1 Introduction

In both civil and military fields, there is a growing interest in timely shared awareness—SA—in multi-platform sensor systems. As a result, there is a growing need for reliable and controlled wireless information sharing in a network centric type approach [4-6]. These techniques can especially help in the case of complex sensors with large amounts of data in complex and dynamic environments, where communication constraints—for example bandwidth and latency—pose significant limitations. In addition to these advanced techniques, evaluation methods can help in that they enable each platform to determine at run-time if information is relevant for the SA and hence should be communicated [8]. In the civil domain this can be useful for a relatively new application as cooperative driving; where cars are in need of near real-time SA of each others kinematic

features in order to react appropriately [10]. Evaluation methods can, at run-time, distinguish less relevant from more relevant kinematic information. In this paper the focus lies on the military field and specifically on maritime operations where multiple ships maintain a time-critical SA of their surroundings.

Currently, the most important military projects that consider network-centric multiplatform wireless data sharing are: CEC—Cooperative Engagement Capability—initiated by the US/UK navy, MPEC—Multi Platform Engagement Capability—initiated by the French defense organization, and LARA—Layered Architecture for Real-time Applications [4]—a joint European program. Although some information is available on these military projects, it is limited and not many details are presented. Most of the available information concerns the LARA project. The results of this project demonstrate that latency is indeed important and can be controlled by reserving enough bandwidth resources. The timeslot-size in case of a Time Division Multiple Access network was also found to be an important issue.

In [8] an approach was presented that enables adaptive communication of information between platforms, see Fig. 1. Local data/information is evaluated by methods that balance the *expected value* of the information for the SA and the *expected cost* of communicating the information to the other platforms. The *expected value* of information is determined by the global information-requests that determine how valuable information is for the SA, and by the expected delay of communication. The *expected cost* of communicating is directly related to the required amount of resources. These evaluation methods are adaptive to, first, changing, and possibly multiple and multi-dimensional requests and, second, to changing communication constraints.

An example of adaptive communication is given in [8], where they aim to construct and maintain a timely SA of the dynamically changing environment between multiple ships. Results of simulation experiments on such a scenario are presented in this paper. The ships are platforms that observe their respective surroundings using

radars and construct shared tracks of the trajectories of objects by concatenating associated detections. Each ship is equipped with the features shown in Fig. 1. An agent—*a* or *b*—periodically receives local radar detections—data. The global information-requests indicate boundaries on the accuracy of the tracks and the delay of updating the SA. The **Eval** shell uses an evaluation method that determines the added value of each detection to the SA—hence how valuable the increase in accuracy is and how valuable the SA is after the expected communication delay—and how costly communicating the detection is to the platforms that share the awareness. When the value outweighs the costs, the detection is communicated by the Communication Service—CS—and incorporated into the SA. The evaluation method adapts, at run-time, the communication to the varying costs, due to changing communication circumstances, and the varying value of detections, due to changing information-requests and impact of detection on the SA.

The evaluation methods therefore rely on accurate and up-to-date communication status information—expected consumption of communication resources and expected latency—influenced by the communication technique and the communication channel. To model, develop and test these evaluation methods, realistic and low-complexity communication models are required that can determine the expected delay distribution—EDD—and the expected cost of communication—ECC. The goal is to bridge the gap between statistical models and the physical understanding of the channel without using complex channel models. In the literature it is hard to find suitable generic, low-complex models and therefore such a model is introduced here.

This low-complexity model derives the EDD and ECC from a certain parameter setting—with parameters like power, frame-time and bandwidth. The model is deliberately made generic but still sufficient in detail to provide EDDs and ECCs of any parameter setting. The advantage is therefore that it can model the behavior of different communication techniques in a broad spectrum of scenarios. Moreover, these models can be used to provide updates of changes in the real-time communication situation, so that the evaluation methods can adapt to these changes. In addition, within the parameter boundaries of the used communication system, the evaluation methods can also use *resource management* to allocate resources to improve the EDDs and ECCs. For example, resource management can re-allocate resources, like adding more power for transmitting a certain message, to change from an unacceptable to an acceptable expected delay. This paper presents a model that determines the probability of latency in terms of the EDD for multicast transmissions. It also

determines the probability of the required resources in terms of the ECC.

This paper starts by pointing out the main performance indicators of communication systems in section 2, to continue with formalizing the communication model descriptions of the EDD and the ECC in section 3. An example, in section 4, shows the benefits of calculating up-to-date EDDs and ECCs and to apply resource management, to finish with a conclusion in section 5.

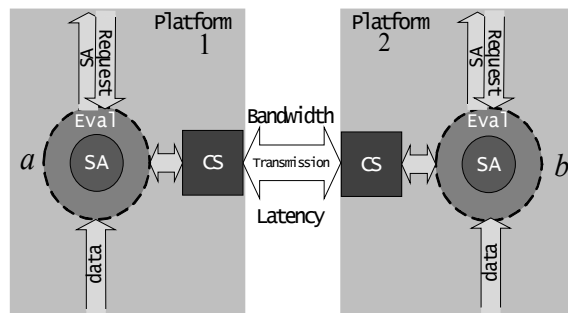


Figure 1. A schematic layout of the distributed construction of SA: Agents *a* and *b* are sharing local data that has been positively evaluated by the **Eval** shell: A higher level agent poses certain information-requests. The **Eval** shell uses these requests and accurate and up-to-date communication status information—delivered by the Communication Service (CS)—to determine whether the value of local data is higher than the communication costs. The **Eval** shell further delivers relevant local data to the CS, which uses a communication system to transmit the data to the other platform. Both agents use the same relevant data to update the SA. Each agent also delivers regular updates of the SA to the higher level agent.

## 2 Communication Constraints

The main performance indicators of wireless communication systems are *link-stability*, *throughput* and *latency*. Link-stability and throughput are mainly constrained due to the signal-to-noise-ratio—SNR—available at the receiver. Parameters that influence the SNR in wireless communication systems are mainly related to transmit power, antenna/array gain (Multiple-Input Multiple-Output (MIMO)/ beamforming), operating frequency, bandwidth, data-rate, modulation format, coding (block, convolution, Reed-Solomon), spread spectrum methods, equalization (inverse channel filtering) and diversity (space, polarization, frequency, time). The system architecture also influences the SNR due to noise figure, system losses, receiver architecture (Intermediate Frequency (IF), conversion, Analog to Digital Converter (ADC)), Radio Frequency (RF) impairments (e.g. phase

noise). Furthermore, the SNR is also influenced by the environment or scenario parameters in terms of propagation losses (path distance, rain, atmospheric conditions) and fading losses (multipath / scintillation, earth curvature, terrain, objects).

The performance in terms of latency can be seen as a second order effect and is influenced mainly by data-rate (bandwidth), time-frame size, packet length, block-code size, guard interval, path delay (propagation distance), bit-error-rate (BER), re-transmissions behavior and network-processing. A model that describes the link-stability, throughput and latency, requires the most dominant parameters related to the above communication properties to be taken into account.

### 3 Communication Model

#### 3.1 Expected Delay Distribution

Latency or delay in communication, caused by constraints in the communication and processing, negatively influences the value of information, especially in time-critical situations. Determining the real-time value of information, therefore, requires knowledge about the current expected delay of communicating information. It is assumed that the communication system has knowledge of the run-time expected delay and error probability of transmitting information. In other words, the communication system is able to determine an Expected Delay Distribution (EDD), which is a distribution of the probability of successful multicast transmissions over time to a set of spatially distributed agents. This distribution is used to determine both the expected cost of communication (ECC) as well as the value of transmitting the information.

To model the probability of delay of transmission by one agent  $i$  to another agent  $j$ , one has to determine the time it takes to transmit the amount of bits that describe the message,  $I$ , and to correctly receive it. Therefore, the SNR at the receiver has to be determined first. The normalized SNR is given in terms of bit-energy-to-noise-energy ratio (Eb/N0) as

$$\frac{Eb}{N0} = \frac{P_i G_i G_j \lambda^2}{(4\pi d)^2 8k T_{sys} R}, \quad (1)$$

where  $\lambda$  is the wavelength,  $P_i$  the effective isotropic radiated power of the transmit antenna,  $G_i$  the transmit antenna gain,  $G_j$  the receive antenna gain,  $L_{sys}$  the system losses,  $R$  the data rate,  $T$  the system temperature,  $d$  the communication distance to agent  $j$ , and  $k$  the Boltzmann constant. Here, an average receiver with circuit noise (twice the thermal noise) is assumed.

From the Eb/N0 ratio, the probability of bit-error can be determined. Rician fading is considered most suitable for a variety of propagation scenarios where Rayleigh fading exists in combination with a strong line-of-sight (LOS) component. The Rician  $K$ -factor is defined as the ratio of signal power in the dominant component over the (local-mean) scattered power. The expected probability of bit-error due to a Rician faded channel using uncoded Binary Phase Shift Keying (BPSK) without diversity can be determined as in [7]:

$$q_e = \left( \frac{1+K}{2+K+E_b/N_0} \right) \exp\left( -\frac{K(1+E_b/N_0)}{2+K+E_b/N_0} \right). \quad (2)$$

The packet-error-probability,  $q_p$ , can be determined from the bit-error-probability as  $q_p = 1 - (1 - q_e)^L$ ,

where  $L$  represents the packet size and it is assumed that a single bit error causes a packet error. Similarly, the time-frame-error-probability,  $q_F$ , can be determined from the packet-error-probability as  $q_F = 1 - (1 - q_p)^K$ , where  $M$  represents the number of packets in a single time-frame. The probability of a *successful* transmission of the total message,  $I$ , for a single transmission attempt by agent  $i$  to agent  $j$  is  $p(j) = (1 - q_F)^F$ , where  $F$  represents the number of time-frames needed to transmit the entire message. For  $N$  transmission attempts the probability of successful transmission after the  $n$ -th transmission to agent  $j$  is  $p(j, n) = (1 - p(j))^{n-1} p(j)$ . For multi-unicast transmissions, i.e., transmissions of the same message to multiple agents, the probability of successful transmission to all agents after the  $n$ -th transmission is  $p(A, n) = (1 - \prod_{j=1}^A p_j)^{n-1} \prod_{j=1}^A p_j$ ,

(3)

where  $A$  represents the set of agents to transmit to.

Now that the probability of successful message transmission can be determined, the corresponding latency or delay should be determined. The latency in a communication link between an agent  $i$  and another agent  $j$  is determined by the data-rate, packet-length, frame-time, round-trip-time (RTT), average packet-error-rate (PER), path delay due to propagation, and the required re-transmissions. Following Fig. 2 the latency is defined as the time between initiation of transmitting message  $I$  with  $M$  packets to the sink,  $t$ , and the reception of a block acknowledgement confirming the arrival of  $I$ , at source  $s$ . The latency of  $N$  transmission attempts to agent  $j$  can be subdivided into determinate (transmit) latency,  $\Delta t_{det}(j, N)$ , and random (receive) latency,  $N t_{RTT}(j)$ . For a unicast/single transmission frame, the latency can be described as

$$\Delta t(j, N) = \Delta t_{det}(j, N) + N t_{RTT}(j), \quad (4)$$

where

$$\Delta t_{det}(j, N) = M t_p + 2 t_{path}(j) + (N - 1)(t_{wait} + M t_p + t_{path}(j)), \quad (5)$$

with packet transmission time

$$t_p = (L/R + t_G), \quad (6)$$

packet size  $L$ , bit rate  $R$ , guard time  $t_G$ , total number of transmission attempts  $N$ , the propagation path delay  $t_{path}$  and back-off delay  $t_{wait}$  due to not receiving an acknowledge message. Here,  $t_{wait}$  is usually defined by a truncated binary back-off algorithm. The RTT follows a Gamma distribution as  $t_{RTT} \sim \Gamma(\alpha, \theta)$ , which is proven to be appropriate for technologies such as 802.11 wireless networks [9]. Typical values are  $\alpha = 2.5$  and  $\theta = 1$ .

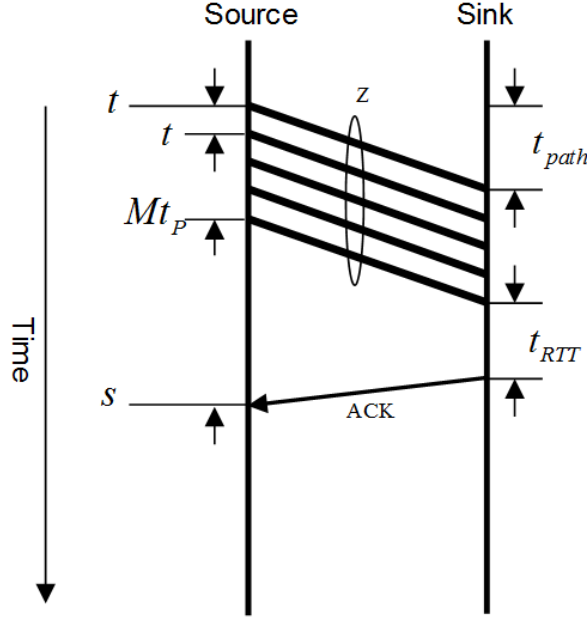


Figure 2. A time-line of a single transmission between a source and a sink.

For a multi-unicast to  $A$  agents, the single-time-frame latency can be described as

$$\Delta t(A, N) = \Delta t_{det}(A, N) + N t_{RTT}, \quad (7)$$

with

$$\begin{aligned} \Delta t_{det}(A, N) = & M t_p + 2 \max_A(t_{path}) + \\ & (N-1)(t_{wait} + M t_p + \max_A(t_{path})) \end{aligned} \quad (8)$$

where the last term signifies the maximum propagation path delay. When the message is spread over multiple time-frames the determinate latency can be described as

$$\begin{aligned} \Delta t_{det}(A, N) = & M t_p + 2 \max_A(t_{path}), \\ & + (N-1)t_{wait} + t_F(F-1)(N-1) \end{aligned} \quad (9)$$

with the frame-time duration  $t_F$ .

When successful message transmission probabilities and latency values are combined, an expected delay distribution—EDD—over time can be constructed for transmission to agents  $A$  over  $N$  transmission attempts,  $E(A, N)$ . During the determinate interval,  $\Delta t_{det}$ , logically, the message will definitely not have arrived at the

agents(s). Therefore, during this time the probability of arrival is zero. After this time, the probability distribution of a single end-to-end link follows a Gamma Cumulative Distribution Function (GCDF),  $G$ , (see the blue line in Fig. 3).

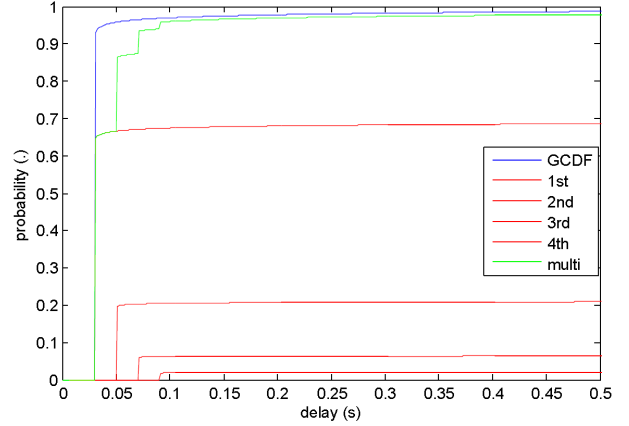


Figure 3. In blue, the time-shifted GCDF of the first transmission attempt,  $G(t - \Delta t_{det}(j, 1))$ . The four red lines represent the time-shifted GCDFs multiplied with the probability of success of the first to the fourth transmission attempt. The green line represents the summed EDDs, calculated by equation 9 with  $N = 4$ .

For  $N$  transmission attempts the GCDF is moved in time by the determinate latency depending on the transmission attempt, multiplied with the probability of success of the transmission attempt and summed for all transmission attempts as

$$E(j, N) = \sum_{n=1}^N p(j, n) G(t - \Delta t_{det}(j, n)). \quad (10)$$

Fig. 3 shows an example of these different GCDFs.

The EDD of  $N$  transmission attempts to agents  $A$ ,  $E(A, N)$ , is as follows: First the product of the separate GCDFs of every unicast to each agent,  $j \in A$ , is taken. This is multiplied with the probability of success of the transmission attempt,  $p(A, n)$ , to result in the EDD of the  $n$ th transmission attempt to agents  $A$ . Finally the EDDs of each transmission attempt are summed:

$$E(A, N) = \sum_n p(A, n) \prod_{j=1}^{|A|} G_j(t - \Delta t_{det}(j, n)). \quad (11)$$

This can be illustrated by Fig. 3 as well, but then imagine the red lines are the 1<sup>st</sup> to the 4<sup>th</sup> multi-cast transmission attempts and the green line is  $E(A, 4)$ .

### 3.2 Expected Cost of Communication

Evaluation methods determine the reward of sending information based on the value of the data and the expected cost of communicating—ECC. The ECC is defined as the amount of resources used over time, with respect to the total amount of resources available. Here,

time is related to the required number of transmission frames,  $F$ , times the number of expected transmissions required,  $N$ . The total ECC is then defined as

$$C(A, N) = FN \frac{TB \sum_{j=1}^A P_j}{T_r P_r B_r} \quad (12)$$

Here,  $T_r$ ,  $P_r$ ,  $B_r$  represent the total available timeslot fraction, power and bandwidth. A communication network has a certain total bandwidth  $B$  available. Assuming that an agent  $i$  has a certain bandwidth  $B_i$  allocated for transmitting a message to agents  $A$ . A larger  $B_i$  claims more of the total bandwidth  $B_r$ , hence is more costly. The same holds for the time slot fraction and the transmission power. Depending on the communication system properties and settings certain resources, such as bandwidth, can be shared among multiple agents.

## 4 Simulation and Results

### 4.1 Wireless Communication

An advantage of the network centric approach of sharing data between sensor platforms is that it can improve SA and coordinated acting. Multiple application domains that maintain SA require timely transmission of large amounts of data. For example, in maritime operations there is a trend from high seas to coastal water operations that are proven to be more difficult. Nowadays the creation of situation awareness in maritime operations is largely platform-centric, and only locally formed complete tracks are communicated to other platforms through inflexible interfaces, such as Link 16. The expansion of coordination between platforms to a lower abstraction level, by exchanging lower-level data than tracks—such as plots, can improve the ability to perform in these complex operations. Advantages of this expansion are, amongst others, an increased chance of detection, a higher accuracy and a better track continuity. On the one hand, sharing the information at a lower level can improve the awareness and acting performance. On the other hand, the amount of information that needs to be shared grows.

The information-sharing network, which connects all the sensor platforms and handles the data exchange, is crucial for the performance of such a system. Highly efficient and interoperable connections that can transmit large amounts of data with low latency are required. A promising (civil) high data-rate terrestrial communication system is Wimax (IEEE 802.16) [3]. Wimax is a fully TCP/IP-based terrestrial point-to-point or point-to-multipoint communication system that can serve multiple subscribers over distances of up to 50 km when using stationary, line-of-sight (LOS) connections. It uses channel bandwidths of 25 MHz to provide data-rates up to 134 Mbps. In the future Wimax will offer data-rates up to 1 Gbps using enhanced MIMO techniques. It can use a variety of

modulation techniques, such as Orthogonal Frequency-Division Multiplexing (OFDM), BPSK, and coding techniques, like convolutional coding, RS coding. For military purposes the NATO has provided NATO band IV (4.4 – 5 GHz) for Wimax operation. Military systems based on Wimax are available and they are capable of sending data up to 37.7 Mbps at 40 km range using 5 Watts of transmit power with up to 64 subscribers [1]. In the next section the system parameters of Wimax are used in the previously presented models as an example. The EDD and ECC are then determined under different conditions.

### 4.2 Example

Assume that four agents,  $a$ ,  $b$ ,  $c$  and  $d$ , are able to share information. Agent  $a$  is linked via link 1 to agent  $b$ , via link 2 to agent  $c$  and via link 3 to agent  $d$ , where the distances to the respective agents are 1, 5, and 15km. Agent  $a$  uses Wimax to communicate and at a certain moment he wants to transmit a message. The question is what the quality of the links between him and the other agents is, and how resource management can help to improve the communication situation resulting in more efficient communication.

The following *fixed* parameter values apply:

- uncoded BPSK modulation;
- transmission frequency:  $F = 4$  Ghz;
- data message:  $LM = 100$ kb;
- packet size:  $L = 128$  bytes;
- power of sender  $i$ :  $P_i = 15$ W;
- antenna gains:  $G_i = 3$ ,  $G_j = 3$ ;
- system losses:  $L_{sys} = 1$ ;
- system temperature:  $T = 300$ K;
- Rician-K factor:  $K = 4$ ;
- guard time:  $t_G = 1$ μs.

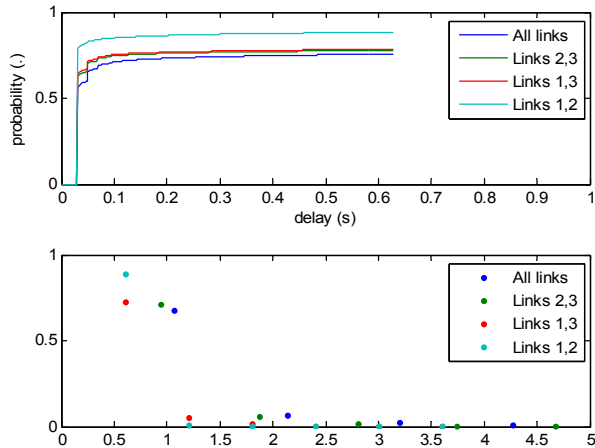
The effect of *varying* parameter values on the EDD and ECC is shown below. In this example the allocated frame-time,  $t_F$ , is set to 10 ms and the bandwidth,  $B$ , to 25 MHz. Resource management changes the frame-time to 1ms and the bandwidth to 12.5 MHz. The EDD (equation 10) and ECC (equation 11) are calculated in both cases for different link combinations: 1 and 2, 1 and 3, 2 and 3.

Figures 4 and 5 show that in the first case the expected costs of communication over all link-combinations is significantly higher, as expected. This means that by allocating a shorter frame-time and smaller bandwidth the ECC is lowered. In addition, a shorter frame-time and smaller bandwidth has both a negative effect as well as a positive effect on the EDD: On the one hand, the absolute latency increases with 21ms from 29ms to 50ms which is

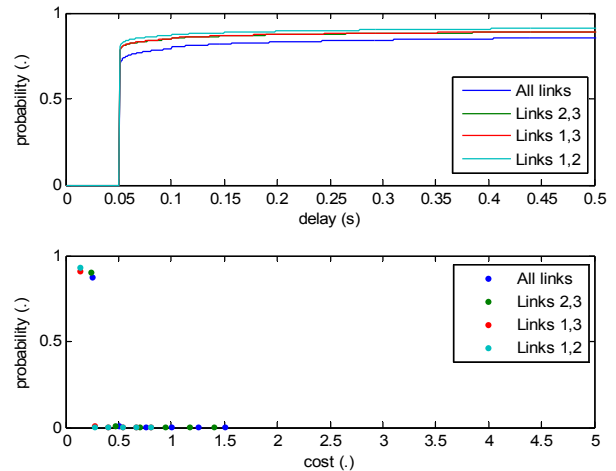
significantly slower; on the other hand, the eventual probability of successful transmission is significantly higher. In other words, the EDD grows worse in absolute delay but improves in probability.

Another observation is that the EDD and ECC are the smallest when link 3 is excluded. The EDD of transmitting over link 1 and 2—the light blue line—is in both situations the best. The ECC over link 1 and 2 is clearly the lowest with a frame-time of 10 ms.

The evaluation methods can use the up-to-date EDD and ECC of the different link-combinations to evaluate the expected value of information for the current Situation Awareness (SA) and expected cost of communicating over different combinations of links. A result may for example be that the evaluation method decides to perform resource management to allocate a frame-time of 1ms instead of 10ms to lower the costs. Another result can be that the evaluation method discards sending the message over link 3 to agent  $d$  so that the delay and costs of communication to agents  $b$  and  $c$  will be lower. In other words, agent  $a$  can estimate the expected costs and expected delay of communication for different receiver-groups, but also for different resource allocations. Moreover it can use these estimations to determine the parameter setting and receiver group which maximizes the value and minimizes the cost.



**Figure 4. EDD and ECC for an allocated frame-time of 10ms and a bandwidth of 25 MHz. The top figure shows the expected delay distribution of communicating over several link-combinations and over all links. The bottom figure shows the expected cost of communication over the same link combinations.**



**Figure 5. EDD and ECC for an allocated frame-time of 1ms and a bandwidth of 12.5 MHz. The top figure shows the expected delay distribution of communicating over several link-combinations and over all links. The bottom figure shows the expected cost of communication over the same link combinations.**

## 5 Conclusions

This article presents a novel low-complexity communication model of the communication system and the communication channel. The model enables simulating accurate and up-to-date communication status information—in this case about the expected consumption of communication resources and expected latency. The most dominant performance indicators are identified and further modeled by formalizing how they are influenced by important parameters. A formal description of the expected delay distribution—EDD—is presented, followed by a formal description of the expected cost of communication—ECC. The simulation example shows that EDDs and ECCs can be estimated for transmitting a message to different receiver groups and they can be used to determine the worst communication link. Evaluation methods can use this information to determine whom to transmit a message to. It also shows that resource management can significantly influence the EDD and ECC. Evaluation methods can therefore use resource management to find the allocation that maximizes the value of information and minimizes the cost of communication.

This model does not consist of the most detailed parameters, but provides the currently most important parameters to enable precise communication information for highly realistic simulations. Such low-complexity models could not be found in the literature. This model is novel in that it enables information evaluation methods to be adaptive to changing communication circumstances. Moreover, the model enables the evaluation of the impact

of different communication techniques on the EDD and ECC. And it also enables the evaluation of the act of allocating certain parameters—i.e., resource management.

The main goal of this paper was to introduce a generic, low-complex communication model that serves as an enabler for evaluation methods. In addition, this model can be used to quickly compare the performance of different communication techniques in different scenarios. It can even be used to test the run-time adaptation of different communication techniques and decide which one to use. For example, some time-critical information can be sent by a low-latency technique—such as Wimax—but other less time-critical information by a high-latency technique—such as Link 16.

## 6 references

- [1] *Bro@dnet information guide*. Technical guide. Telefunken. 2008.
- [2] IEEE 802.16 Broadband Wireless Access Working Group. 2006. *Multihop System Evaluation Methodology: Traffic Models*. May 1, 2006day.
- [3] IEEE 802.16 Broadband Wireless Access Working Group. 2002. *IEEE Standard for Local and Metropolitan Area Networks — Part 16: Air Interface for Fixed Broadband Wireless Access Systems*. (Apr. 8, 2002).
- [4] Thebault, D. 2007. *LARA Executive Summary*, (Sept. 18, 2007).
- [5] National Research Council Washington Dc Naval Studies Board. 2000. *Network-Centric Naval Forces: A Transition Strategy for Enhancing Operational Capabilities*. National Academy Press.
- [6] Nolin, P.C. 2007. *Transforming the future of warfare: network-enabled capabilities and unmanned systems*. 2007 annual session of the NATO Parliamentary Assembly.
- [7] Simon, M. K., Alouini, M. 2005. *Digital communication over fading channels*. Wiley, New Jersey.
- [8] van Foeken, E., Kester, L., Iersel, M. 2009. *Real-Time Common Awareness in Communication Constrained Sensor Systems*. 12th International Conference on Information Fusion 2009, Seattle, USA.
- [9] Xu et al. 2008. Latency Estimation for Time-Sensitive Applications under Wireless Network Coding Scheme. *IEEE Int. conf. on Communications and Mobile Computing*. (Jan. 2008), 263-266.
- [10] Röckl, Matthias and Frank, Korbinian and Robertson, Patrick and Strang, Thomas (2006) [Enhancing Driver Assistance Systems by Cooperative Situation Awareness](#). In: Proceedings. DGON-Symposium: System Verkehr - Steuern, Regeln, Entwickeln, 2006-11-29 - 2006-11-30, Göttingen, Germany.