14

A Unified Data and Energy Model for Wireless Communication with Moving Senders and Fixed Receivers

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1. Introduction

In recent years, the question of energy efficiency in ICT solutions has grown to a hot topic, both in research and in product development. Especially for applications in the field the efficient use of the available (stored or newly generated) energy is a precondition for the desired functionality. Energy wasting is not only a question of expenses or of impacts to the environment, but in many cases simply precludes the proper working of a sensor/actuator control system.

Our research group has conducted several research projects during the last years in the area of protocol optimisation in order to increase energy efficiency of wireless communication. First we developed an energy model to conduct simulations which describe the energy consumption of sending a well defined amount of data over a wireless link with fixed properties. As variable parameters of this model we used the transmission power of the sending antenna and the packet length of the transmitted data. This model already included a stochastic part: The loss of the transmitted packets. The packet loss probability was evidently dependent on the sending power. So far we followed the model of the group around J.P. Ebert and A. Wolisz (Ebert et al., 2000; Ebert et al., 2002).

We then integrated a data model to simulate the amount of newly produced data respectively data that has remained in the sending buffer, thus we generated a unified data and energy model. Finally we integrated a distance model to simulate the changing distances between the sender and the receiver. As a matter of simplicity (but without spoiling the capabilities of the model) we assumed that the receiver is fixed, and the sender is moving (Veichtlbauer & Dorfinger, 2007).

We conducted our research work within funded research projects: Autarchic Ski (ASki), GI Platform Salzburg and the GI Tech Lab, all of them funded by the Austrian Federal Ministry for Transport, Innovation, and Technology, in different funding schemes. Along with the different projects came different application scenarios, e.g. the communication of intelligent skis (which have sensors on board to measure for instance temperature or pressure during runs) with base stations which analyse the collected sensor data (Veichtlbauer & Dorfinger, 2008; Veichtlbauer & Dorfinger, 2009) or the collaboration of a swarm of flying sensors (Dorfinger & Veichtlbauer, 2008) for weather or gas density measurements.

2. Description of the Model

Our MATLAB/Simulink based „Unified Data and Energy Model" for wireless communication takes into account both its energy and its data balance, i.e. it calculates the amount of successfully transmitted and lost data per time unit and contrasts these values with the consumed energy.

2.1 Modelling Approach

The goal in our setting was to maximize the amount of successfully transmitted data in surroundings where energy is a scarce resource. For static scenarios (constant distance between sender and receiver) a well proven model can be found in literature: The model of J. P. Ebert and his team. Their mathematical analysis of wireless communication is based on the Link Budget Analysis of Zyren and Petrik (Zyren & Petrik, 1998) and the Gilbert-Elliot Bit Error Model (Gilbert, 1960).

The basic idea of Ebert's model is to calculate an "energy per bit" value to quantify the needed energy for the successful transmission of one bit, and to minimize this energy by changing the sending power. He proves that with variation of sending power and keeping all other parameters (like packet length, distance between sender and receiver, receiver gain, etc.) constant, such a minimum can be found: Obviously, increasing sending power leads to higher energy consumption of the sending attempts. On the other hand decreasing sending power leads to increasing loss probability of a transmitted packet, thus causing retransmissions of the lost packets (Ebert & Wolisz, 1999; Ebert & Wolisz, 2000; Burns & Ebert, 2001). Using appropriate simulations, an optimum can be found easily.

This approach can be applied for multi-hop ad-hoc networks (Matzen et al., 2003; Ebert, 2004), considering different routes and using the shortest links to save energy (the energy per bit value is lower for shorter distances), yet the dynamics (changing distances between nodes) are still not considered. It is possible to send packets with well calculated sending power at any time, but all data are sent immediately after their "production" (e.g. by sensors which measure periodically some environmental parameters).

In our scenarios we considered a moving sender and (one or more) fixed receiver(s). For a moving sender, it is profitable to consider also the sending times: Sending at the moment of minimal distance will optimise the energy per bit value. Thus, we integrated a distance model into our approach. The idea is to predict the further movement and to send during the time(s), when the sender is closest to the receiver(s).

We used a time discrete approach for our model, as the data generation is done that way by the sensors (depending on their sampling rate). Although we use the packet length as an input factor, we do not use packet simulations. Bit errors influence the data flows in a statistical manner, thus our model complies with the approach of Haber et al. (Haber et al., 2003) for fluid simulations of data streams.

2.2 Model Assumptions

The basic assumptions for our model are:

- Energy is stored in capacitors of a defined size; the efficiency of storing energy is dependent on the filling level of the capacitors.
- A data buffer storage of a defined size is used on the sender side to store some sensor data.
- The data storage is organised as a ring buffer, thus a full storage will lead to data loss (new data is written over old data which has not been successfully transmitted on time).
- The optimization criterion is given by amount of successfully transmitted data (with given energy).
- The adjustable parameters are: The sending power, the packet length and the sending time(s).

Sending power and packet length are optimized according to the Ebert model. To take into account the dynamics of the movement, we do not send immediately, but store the produced data in the local buffer and calculate the optimal sending times according to the distance model. Our approach is simple, but effective: We calculate whether the sender is approaching or departing a base station. In the first case we are waiting, in the latter case we are sending data (with some constraints, see below: sending strategy).

Additionally we integrated a sub-model for the energy production side, although being logically independent from the optimisation strategy. The reasons for this are first the fact that the time of energy generation has direct influence on the optimisation result and second the complex constraints in storing energy, especially when using capacitors.

2.3 Sending Strategy

This strategy makes implicit predictions about the further movement: If the sender has been approaching a base station during the last period, the predicted value for the further movement in the next period is a further approach (thus, sending later will be more efficient due to lower distances). If the sender has been departing during the last period, the predicted value for the further movement in the next period is a further departure (thus, sending later will be less efficient due to higher distances).

The downside of this strategy is the transmission delay of the sensor data. As we are waiting for energy optimal conditions, we can not guarantee maximum delay values, thus this approach is clearly not real-time capable. However in field surroundings which are naturally unsafe (the successful transmission can not be guaranteed anyway due to the sparse available energy) this drawback seems acceptable for us.

There are some other constraints in our sending strategy which shall ensure an efficient use of the available energy:

- Loss Threshold: If the probability of a packet loss is above a predefined threshold (which is the case for instance if the distance between sender and receiver is too long), we do not attempt to send.
- Data Threshold: If the amount of stored data increases a threshold (which is set to data buffer capacity minus the amount of newly produced data per time unit here, meaning that after the next cycle data loss can be expected, if no data can be successfully transmitted), we are sending data regardless the movement to or from a receiving base stations.
- Upper and Lower Energy Threshold: If the filling level of the energy storage exceeds an upper energy threshold, we make a sending attempt regardless the

movement of the sender, provided that energy level after sending is not expected to fall below a lower energy threshold. The reason for the upper threshold is that we might not be able to store the newly produced energy in the energy storage (e.g. capacitors), when the storage is already charged too high (see below: energy management). The reason for the lower threshold is that sending attempts at great distances would lead to almost emptying the storage at just one cycle tick. Especially in scenarios with few newly produced energy (see below: simulation scenarios) this could cause a sending inability even at energetically auspicious situations.

Figure 1 shows the flow chart of the sending strategy:

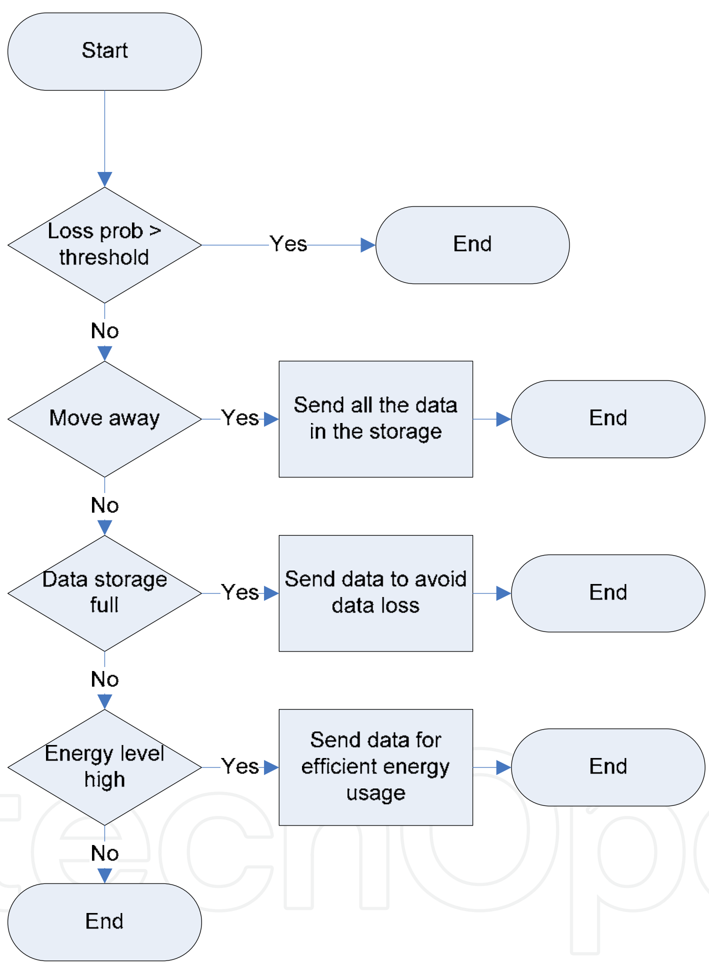

Fig. 1. Sending strategy flow chart

2.4 Simulation Scenarios

We applied our model to several practical application scenarios:

- The skiing scenario (Veichtlbauer & Dorfinger, 2007): A skier is equipped with intelligent skis with integrated sensors and energy harvesters. The sensors collect data in regularly intervals and store them in the local buffer. The energy harvesters produce energy during the run, e.g. by electromagnetic induction (EnOcean, 2007).

The energy generation is dependent on the movement (see fig.2). The energy is used to transmit the sensor data to a single fixed receiver.

- The cloud scenario (Dorfinger & Veichtlbauer, 2008): 20 Sensors are placed by an aeroplane to perform several measurement tasks in the air. They communicate with a grid of 16 fixed receivers on the ground, forming a 4.5 x 4.5 km square in total. Energy is stored in capacitors with total capacity of 600 µF. They are fully loaded at the start of their operation, i.e. they have an initial voltage of 12 V. No new energy is generated during the operation.

In order to examine the results of our model approach in different environments, we conducted several simulations with these scenarios. For the skiing scenario we made some additional assumptions (see above: model assumptions):

- The sender moves in different moving patterns along the fixed receiver (WLAN base station): We used straight moves, 2 different sine curves and a combination of sine and straight movement (see fig. 2).
- Energy is generated only at the sine parts (with 4 "passes" per second). The amount of produced energy per pass (see below: energy management) on the sender side is constant.
- For storing the energy (see below: energy management) we used 5 capacitors with 47 µF capacity each.
- The amount of produced (sensor) data per pass (and thus per time unit) on the sender side is constant.

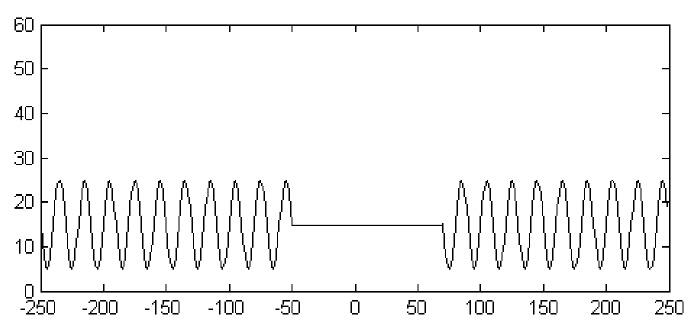

Fig. 2. Movement pattern of skiing scenario

2.5 Energy Management

For those scenarios where new energy is produced during operation (e.g. the skiing scenario) we assumed that the energy is provided by an energy harvester, e.g. the ECO 100 from EnOcean (EnOcean, 2007). This was motivated by our work in the project ASki where we built a prototype for the skiing scenario with an energy harvester placed on a ski. For those scenarios where all energy is pre-loaded (e.g. the cloud scenario) we used the same model, just setting the amount of energy generated during operation to zero.

The energy harvester is able to provide a voltage (see fig. 3) showing periodical peaks ("passes"). The original voltage pulse (green) is approximated by a triangle voltage (yellow), which is assumed to be our input voltage curve. The triangle voltage is described by the maximum input voltage and the duration of the pass. This model can be easily adapted to work with any kind of periodical energy source.

When using capacitors, energy can only be stored provided that the voltage of the produced energy is higher than the current voltage level in the capacitor (red). Thus, for all scenarios where we are able to produce new energy in the field, it is beneficial to keep the energy filling status on a lower level, as it is easier to charge the capacitors then. This can be done by setting the upper energy threshold to a comparatively lower level. The amount of energy which can be stored in capacitors is modelled in an extra sub-model (see below: energy storage model).
If we do not produce new energy, but use only stored energy from external sources, this constraint will be kept inactive by setting the upper energy threshold to the energy storing capacity (see above: sending strategy). Hence it is possible to use the same model without changes.

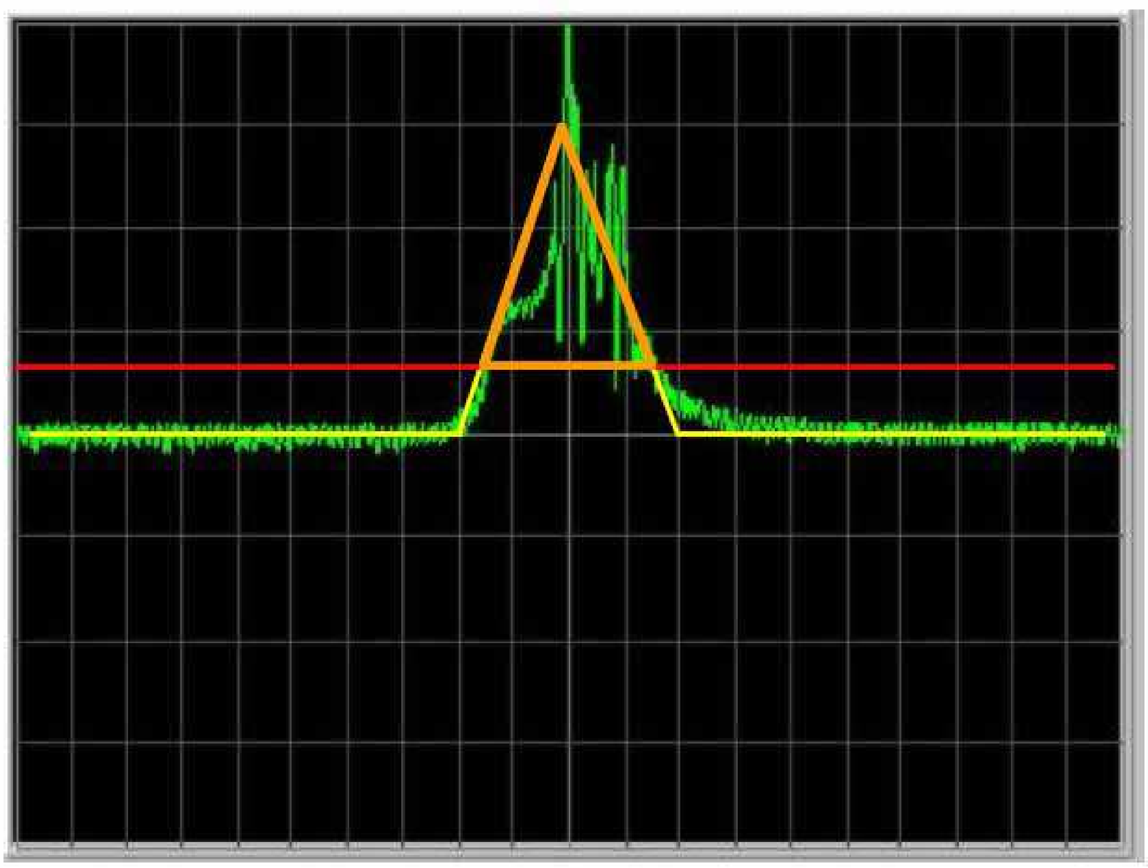

Fig. 3. Useable energy of triangle voltage

The amount of consumed energy per transferred bit is first dependent on the sending power. Second the packet loss probability has influence, because lost packets have to be retransmitted. The occurrence of a packet loss is dependent on the distance between sender and receiver, the packet length (Pl) as well as on the sending power. Yet it is a stochastic event, which has to be modelled properly (see below: loss model).
The probability of a packet loss is called packet error rate (PER). It is calculated based on the bit error rate (BER): $PER = (1-(1-BER)^{Pl})$. In the simulations we used a random number

based on PER to determine whether the packet has been transmitted correctly or not. If the data is received correctly, it can be deleted from the sender's data storage.

3. Implementation of the Model

In the following our basic model and all of its sub-components (blocks) are described in detail. As model description language MATLAB/Simulink was used.

3.1 Basic Model

Our basic model consists of two main blocks (see fig. 4): The Energy Storage block, where the energy generation and energy storage behaviour is modelled (see below: Energy storage model), and the Energy Cons block (see below: Energy consumption model) modelling the energy consumption of the WLAN sender. The model has three input parameters:

- The energy produced during the last time interval
- The data produced by the sensors during the last time interval
- The current distance between the WLAN sender and the base station

The main interest is to successfully transmit as many data as possible. Furthermore we want to keep the amount of data that is overwritten in the data storage before being successfully transmitted (which is lost then) minimal. Consequently the output parameters of our basic model are:

- The aggregate of received data over simulation time
- The aggregate of overwritten (lost) data over simulation time

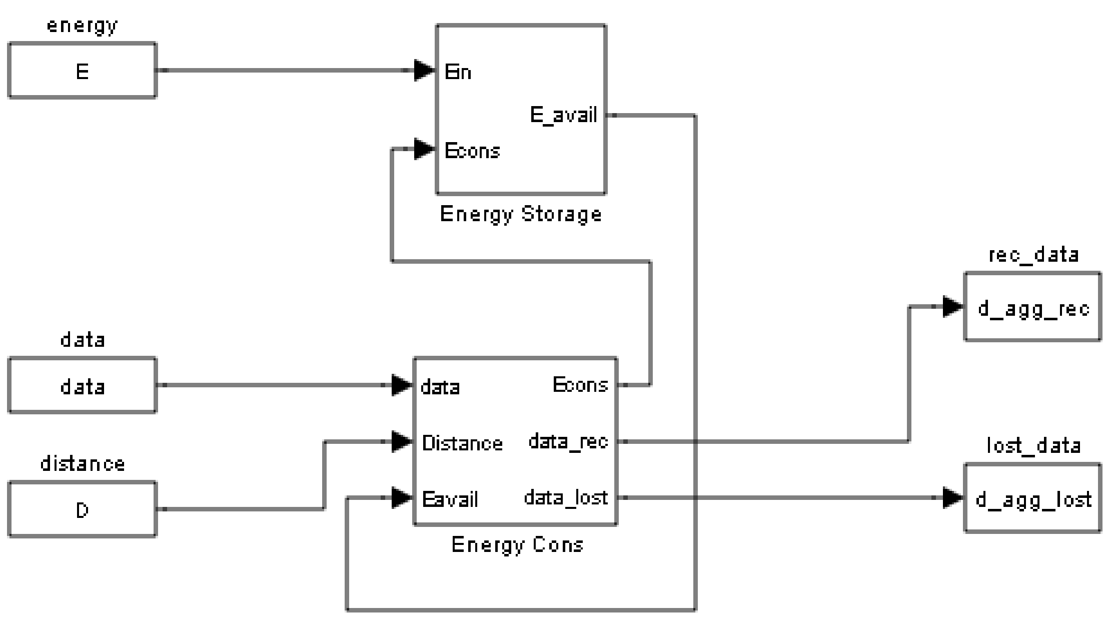

Fig. 4. Basic Model

3.2 Energy Storage Model

The main building block of the energy storage model (see fig.5) is a MATLAB function that calculates the current energy in the storage. As input parameter the model gets the energy produced during the last time interval (Ein) and the energy consumed during the last interval (Econs). The output is the available energy for transmission (E_avail).
For energy production we use an energy harvester (EnOcean, 2007); for energy storage we use common capacitors. The model uses the following parameters:

- Total capacity of the capacitors (C)
- Resistance of capacitor (Rc)
- Maximum voltage of energy triangle (Ugmax)
- Duration of the energy pass (dur_pass)
- Minimum voltage difference between energy source and capacitor that is needed to load the capacitors (Uckorr)
- Energy per pass (Ep)
- Maximum energy that can be stored in the capacitors (Estoremax)
- Minimum energy in capacitors, i.e. energy that remains in capacitors and can not be used by energy consumers (Estoremin)

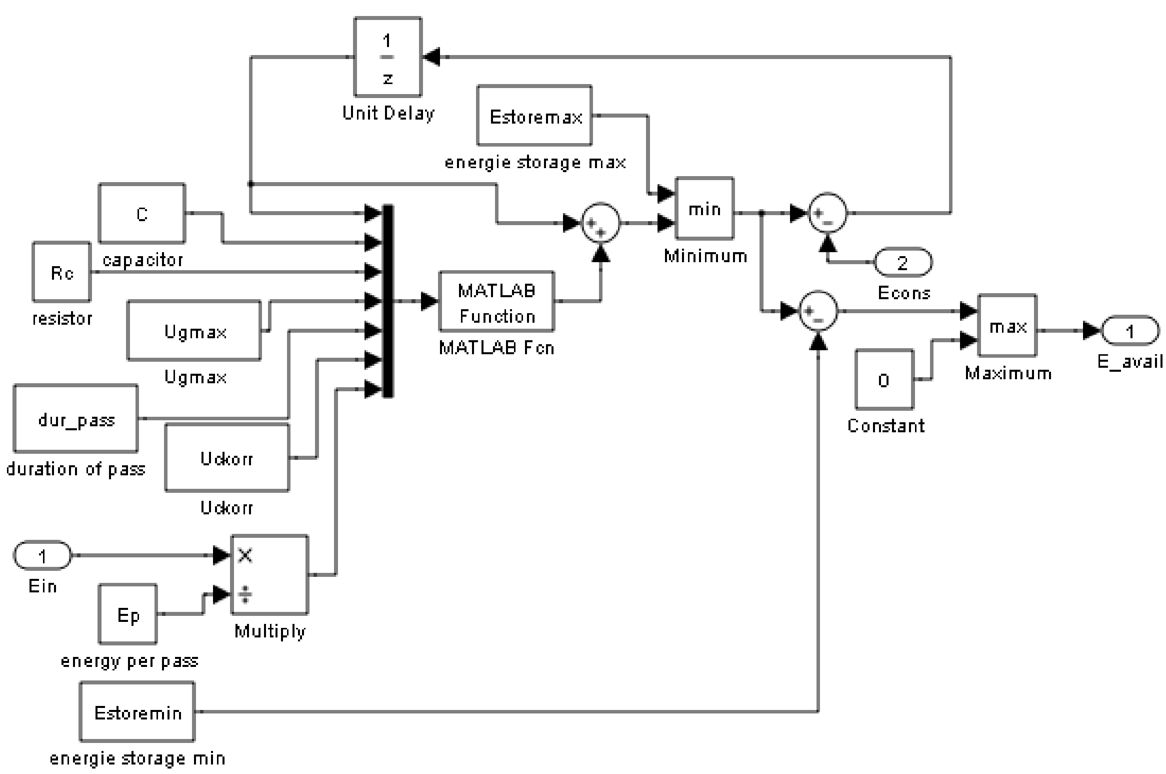

Fig. 5. Energy Storage Model

3.3 Energy Consumption Model

The energy consumption model (see fig. 6) consists of 6 main blocks:

- Distance model (Dist_model): Prediction of the further movement of the sender and calculation of the sending position

- Parameter model (`ideal send param`): Calculation of ideal parameters for data transmission
- Data storage (`data storage`): Calculation of the current filling level of the data buffer storage
- Sending decision (`send data?`): Decision whether to send data in the next time slot or not
- Link loss model (`link loss`): Determination of successfully transmitted and corrupted data packets (which have to be retransmitted and can not be deleted from the data storage)
- Data aggregation (`Aggregate`): Aggregation of successfully transmitted and lost data bits

Input signals for the energy consumption model are: The current distance (`Distance`), the data produced during the last interval (`data`) and the available energy from the energy storage (`Eavail`).

Output signals are: The consumed energy (`Econs`), the data successfully transmitted to the base station (`data_rec`) and the data lost by overwriting them in the data storage (`data_lost`).

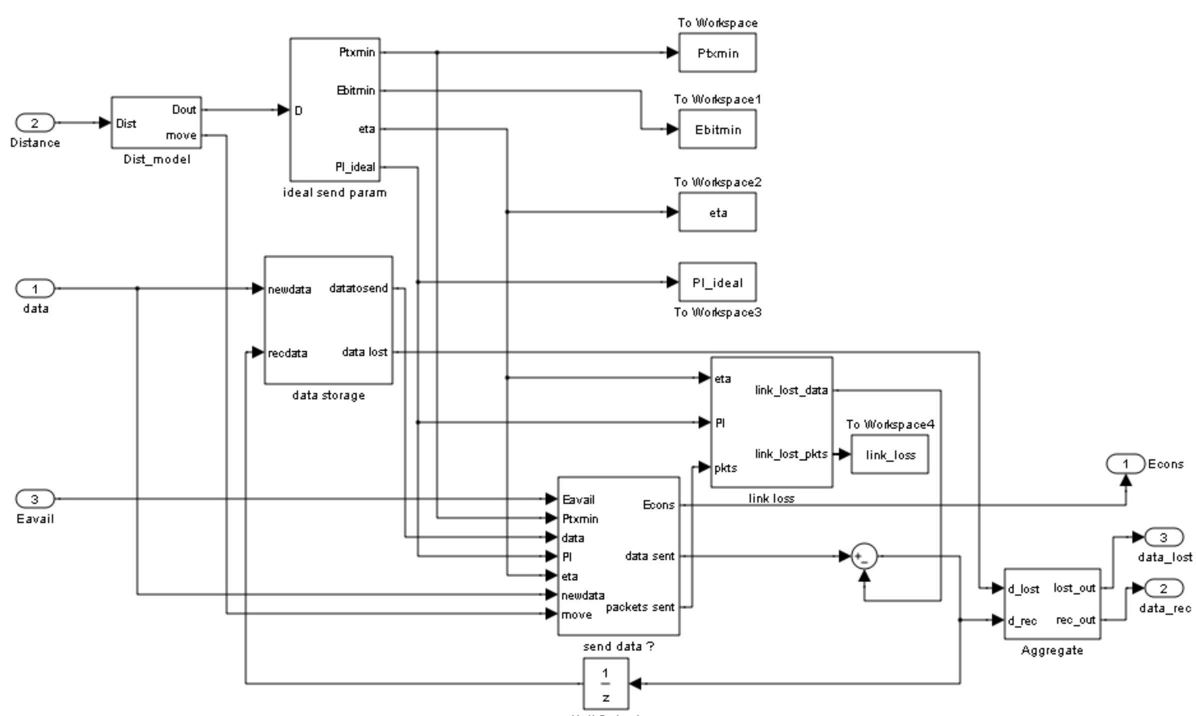

Fig. 6. Energy Consumption Model

3.4 Distance Model

The distance model (see fig. 7) calculates whether the sender is moving towards the base station or departing from the receiver by comparing the current distance with the distance of the previous clock cycle and assuming that the movement continues that way also for the upcoming cycle time. From that movement prediction the sending distance (which is then used for the calculation of the other sending parameters) is derived.

As argued by Ebert (Ebert, 2004), it is better to overestimate the distance than to underestimate it, because the sending power adaptation is not symmetric: If the sending power is too low, the loss probability (and thus the energy per *correct* transmitted bit) increases much faster than the energy per sent packet increases in the case when the sending power is too high.
Consequently for a movement towards the base station the output value for the distance is the current position, whereas for a movement departing from the base station the output value is an estimation of the position at the end of the time interval. As it is assumed that the movement continues the same way as in the last time interval, the estimated position is the current position plus the movement during the last time interval.

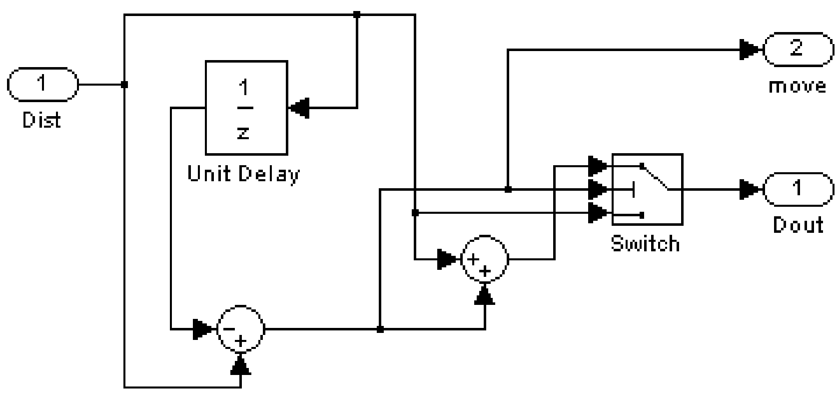

Fig. 7. Distance Model

3.5 Parameter Model

The parameter model consists basically of a MATLAB function which calculates the ideal sending parameters based on the Ebert model (Ebert, 2004).
As input parameters the MATLAB function receives technical parameters describing the WLAN connection: Sender gain, receiver gain, fade margin, receiver noise, bandwidth, sending rate, loss threshold, sending duration for 1 bit, wave length, noise, maximum packet size without header, overhead, and a correction constant. We kept these parameters constant in our simulations, yet they could easily be varied over time by setting appropriate values in the MATLAB configuration file. Furthermore the distance between sender and receiver is used as variable input parameter to the parameter model.
As output parameter we retrieve the ideal sending power (`Ptxmin`), the energy needed for transmission of one bit (`Ebitmin`), the probability that a packet is successfully transmitted (`eta`) and the ideal packet length for the transmission (`Pl_ideal`).

3.6 Data Storage Model

The data storage model calculates the current filling status of the data buffer storage by subtracting the data which has been successfully transmitted in the last time interval (`rec_data`) from last cycle's filling level and adding the data which has been newly produced during the last time interval (`newdata`). These two values are the input parameters of the data storage model.

The storage has a maximum size (`datamax`), and is organised as a ring buffer, i.e. exceeding the maximum value leads to data loss by overwriting the oldest stored data with the newly produced data. Hence the output parameters are the filling level, i.e. the amount of data which can be transmitted in this time interval (`datatosend`), and the amount of overwritten data (`data lost`).

3.7 Sending Decision Model

The sending decision model (see fig. 8) calculates the amount of data that are sent in the upcoming time interval.

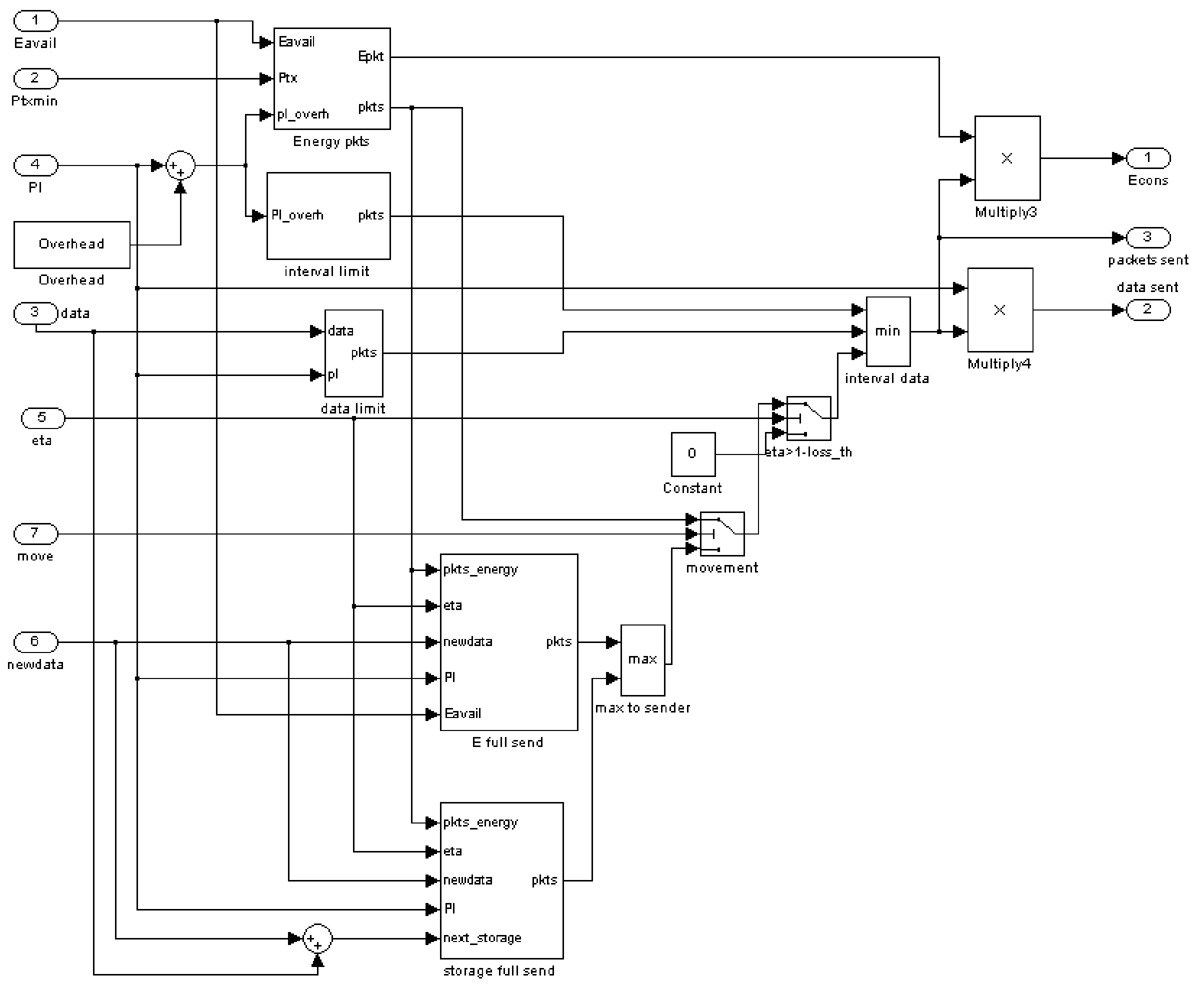

Fig. 8. Sending Decision Model

It consists of five sub-models; each of them determines the number of packets that could be sent taking into account different premises:

- How many packets can be transmitted if all the available energy is spent for transmission?
- How many packets can be transmitted within one time interval?
- How many packets can be filled with data from the storage?

- How many packets should be transmitted to allow efficient usage of the energy storage?
- How many packets should be transmitted to prevent overwriting data in the data storage?

The model provides us with three outputs:

- The consumed energy
- The sent data
- The number of sent packets

The number of sent packets is zero if the probability of a packet loss on the link is greater than a given threshold (see above: sending strategy).
If we are moving away from the base station, all data in the data storage are sent, except for the rest that does not fill a full packet with ideal packet length. Thereby we are taking into account the maximum amount of data that can be sent with the available energy and within one time interval. If we are moving towards the base station the same energy and time constraints are taken into account; furthermore we pay attention to the objectives to prevent data loss in the data storage and to allow efficient energy storage (see above: energy management).
In the next sub-sections some details about the main building blocks, including their input and output parameters, are given.

3.8 Packet Energy Model

The packet energy building block (see fig. 9) receives the following input signals: The available energy (`Eavail`), the ideal transmission power (`Ptx`), and the packet length including overhead (`pl_overh`).
Output variables are: The energy per packet (`Epkt`), and the number of packets that can be transmitted when consuming all available energy in the energy storage (pkts).

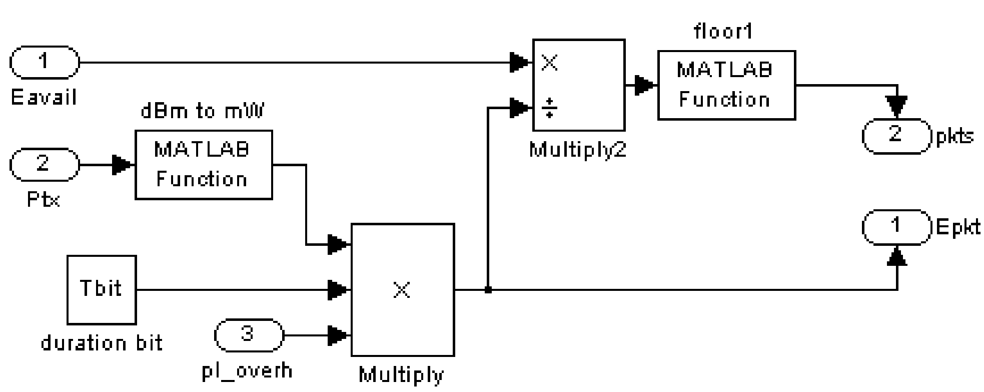

Fig. 9. Packet Energy Model

3.9 Interval Limit Model

The interval limit building block receives the packet length including overhead as input parameter. It calculates the number of whole packets that can be sent within one time interval, which is also the only output parameter.

3.10 Data Limit Model

The data limit building block has the following input parameters: The current level of data in the data buffer storage, and the packet length without header. It calculates the number of packets that can be filled with data from the storage. This is the only output parameter of the data limit model.

3.11 Energy Efficiency Model

To make energy usage more efficient (see above: sending strategy), we use the energy efficiency model (see fig. 10).

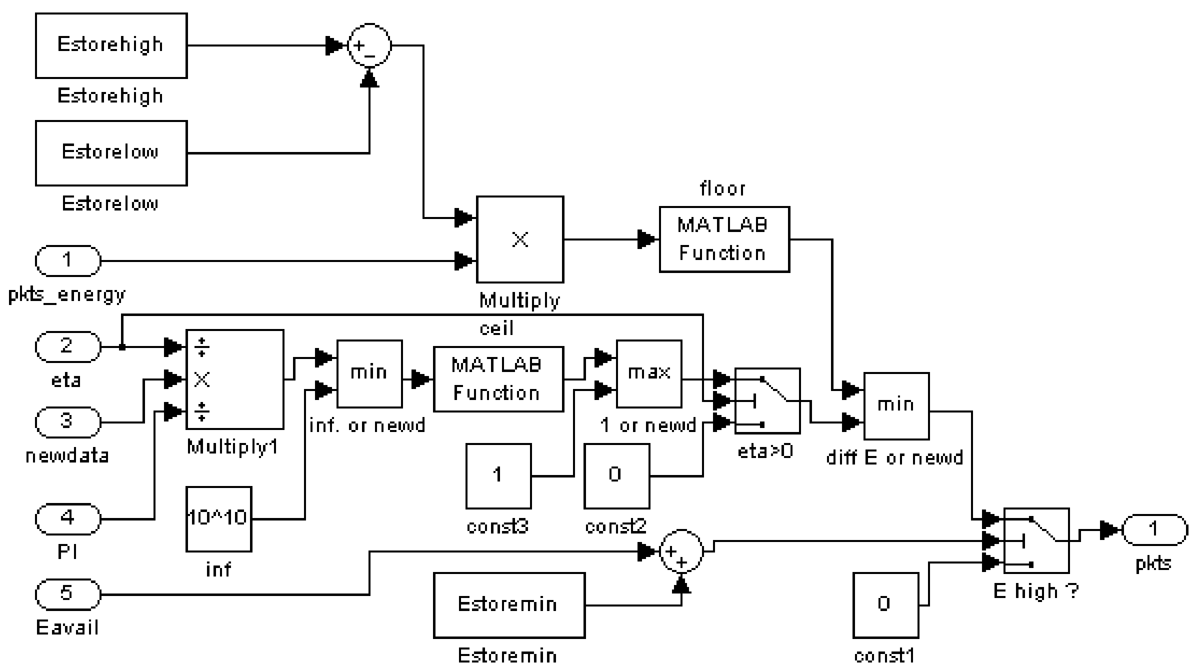

Fig. 10. Energy Efficiency Model

If the energy in the storage is above an upper threshold (`Estorehigh`), we transmit `ceil(1/eta*newdata/Pl)` packets, where `eta` is the probability that a transmission is successful, `newdata` is the amount of data stored in the last interval and `Pl` is the ideal packet length without header.
Thereby we have to guarantee, that the energy stored in the capacitors does not fall below a lower threshold (`Estorelow`) after data transmission, i.e. we transmit the maximum possible number of packets such that the energy consumption by the data transmission is low enough to keep this constraint.

3.12 Data Efficiency Model

The data efficiency model (see fig. 11) is used to prevent data loss in the storage during the time when the sender is moving towards the base station.

If the amount of data in the storage plus the amount of data received in the upcoming time interval is expected to exceed the capacity of the storage, we transmit a number of `ceil(1/eta*newdata/Pl)` packets.

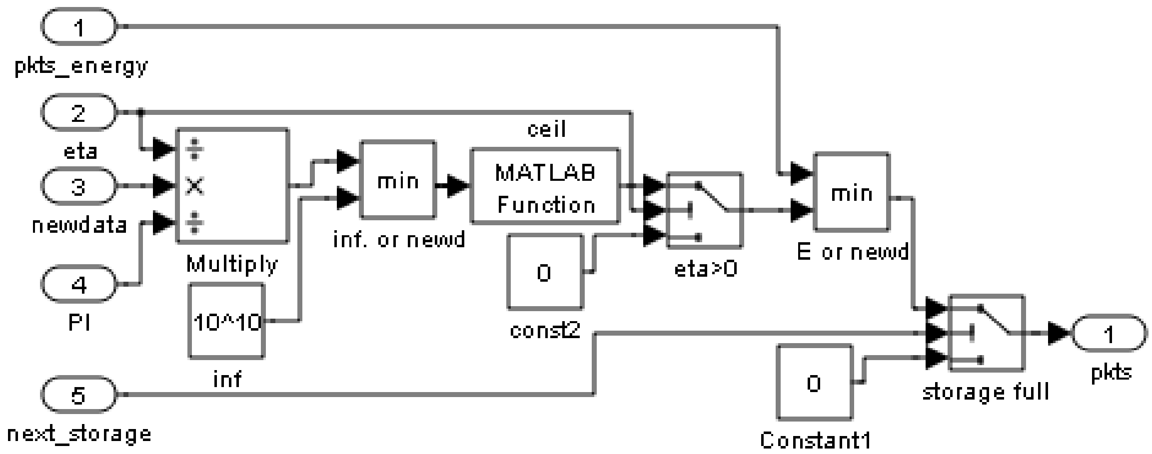

Fig. 11. Data Efficiency Model

The data efficiency model receives as input parameters: The number of packets that can be sent with all available energy (`pkts_energy`), the probability that a packet is successfully transmitted (`eta`), the data received in the last interval (`newdata`), the packet length (`Pl`) and a prediction of the next filling level of the data storage (`next_storage`). The output parameter is the number of packets that should be transmitted (`pkts`).

4. Parameter Tuning

In a number of simulations we have investigated the advantages of this model approach compared to the Ebert model and to a non-optimised episodic protocol (Veichtlbauer & Dorfinger, 2007; Dorfinger & Veichtlbauer, 2008; Veichtlbauer & Dorfinger, 2008). With optimal parameter settings however, some percent additional efficiency gain could be achieved.

To investigate the influence of different settings, several studies in the skiing environment have been performed. Thereby the setup of the main factors that influence throughput and data loss has been studied:

- Capacity of energy storage
- Size of data storage
- Energy threshold
- Loss threshold

For the simulation with different sizes of energy and data storages we got the expected results: The bigger the storage, the greater the number of successfully transmitted packets, and the lower the packet loss. For the setting of the energy thresholds we got similar results for different parameter sets. In the performed scenarios there is no strong argument for a certain parameter set of the energy thresholds.

The most interesting parameter in our simulations of the skiing scenario was the loss threshold. We conducted simulation runs with several different movements, e.g. a straight movement (see fig. 12, table 1) and a sine movement (see fig. 13, table 2).

Table 1 shows statistical results for different values of loss threshold in the skiing scenario with straight movement. For each value 100 simulation runs have been performed.

Loss_th	mean	standard dev.	95% confidence interval	min	max
1.0	4.373.680	22.115	[4.369.346, 4.378.014]	4.330.832	4.443.256
0.9	4.365.656	22.223	[4.361.300, 4.370.011]	4.313.576	4.444.368
0.5	4.342.520	25.479	[4.337.526, 4.347.514]	4.273.690	4.401.360
0.3	4.292.992	22.868	[4.288.509, 4.297.474]	4.241.280	4.347.520
0.1	4.136.336	19.153	[4.132.582, 4.140.897]	4.090.376	4.192.672

Table 1. Throughput for different values of loss threshold with straight movement

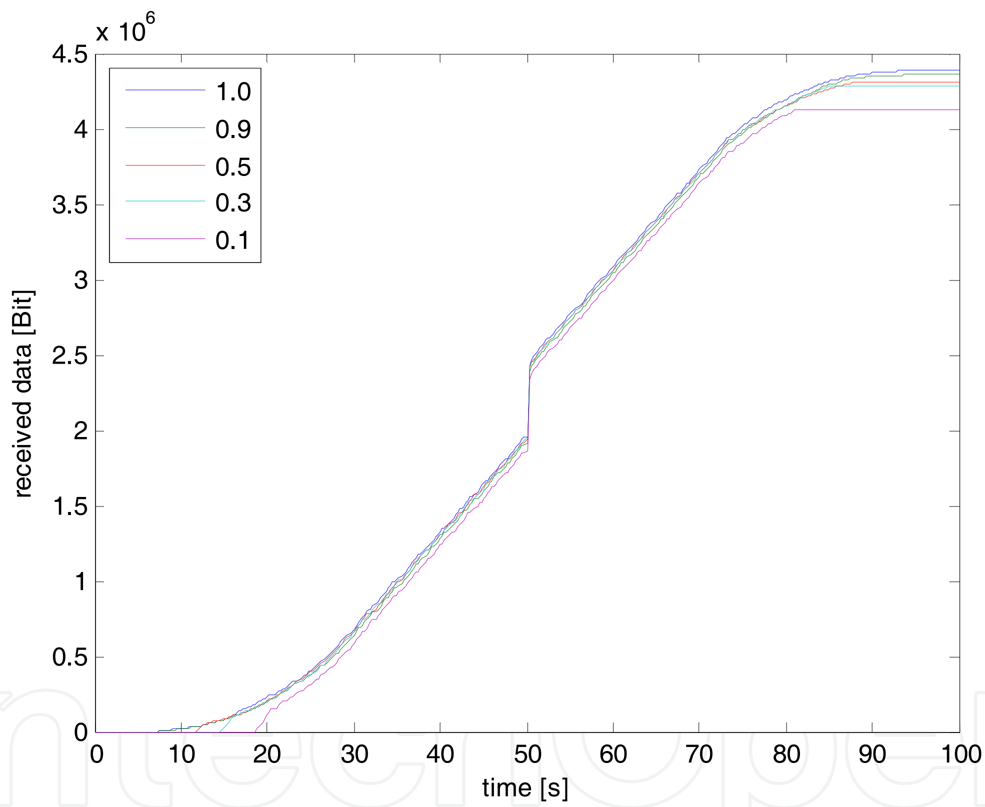

Fig. 12. Received data for different values of loss threshold with straight movement

As it can be seen, the lower the loss threshold is set, the less data is received. A detailed analysis has shown that it would be beneficial to use different settings for loss threshold in the approaching phase and in the departing phase of a simulation of the skiing scenario: During the approaching phase a loss threshold of about 0.9 would perform best. During the departure phase transmission attempts should be performed as long as there is a possibility to successfully transmit data packets, thus the loss threshold should be set to 1.

Table 2 shows statistical results for different values of loss threshold in the skiing scenario with sine movement. Again, for each value 100 simulation runs have been performed.

Loss_th	mean	Standard dev.	95% confidence interval	min	max
1.0	4.357.283	22.628	[4.352.848, 4.361.718]	4.304.752	4.401.944
0.9	4.356.078	21.182	[4.351.926, 4.360.230]	4.311.872	4.400.640
0.5	4.336.494	23.374	[4.331.913, 4.341.076]	4.269.368	4.386.384
0.3	4.277.693	22.323	[4.273.317, 4.282.068]	4.215.872	4.343.960
0.1	4.118.336	21.435	[4.114.134, 4.122.537]	4.038.416	4.154.080

Table 2. Throughput for different values of loss threshold with sine movement

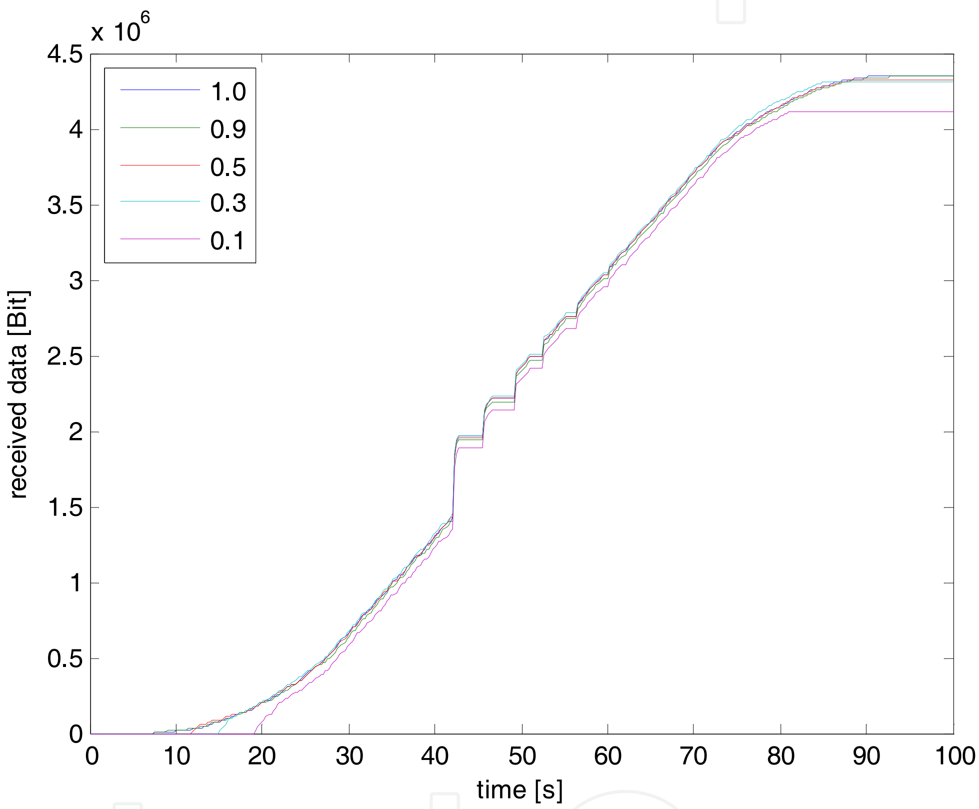

Fig. 13. Received data for different values of loss threshold with sine movement

Also for the sine movement pattern in the skiing scenario a loss threshold of 1 performs best. This is in contrast to our findings for the cloud scenario (Veichtlbauer & Dorfinger, 2008), where we concluded that for pre-loaded energy sources smaller values for the loss threshold lead to better performance.

An overall conclusion of our investigations in setting the loss threshold parameter is that it depends very strongly on the kind of energy source how to optimise the parameter setting. For pre-loaded energy sources with no further energy generation during the simulation a small value for the loss threshold is advisable, whereas for energy sources that supply energy during the run (energy harvesters) a loss threshold near to 1 should be used.

5. Conclusion

As a result of our simulations we can see a remarkable improvement (Veichtlbauer & Dorfinger, 2007; Dorfinger & Veichtlbauer, 2008) of the use of energy compared with the underlying Ebert model (Ebert, 2004). Yet the efficiency gain is very much dependent on the applied scenario. Especially in scenarios where energy is produced regularly during the operation of the communication system, the gain is only a few percent.
However, energy efficiency is a much more critical issue in scenarios where no or only sporadic energy production is possible. Our model has been developed for mobile scenarios with sparse energy. Here the strengths of our approach come into effect, as we have proved in the mentioned examples.

6. Future Work

Obviously, energy is consumed not only by (sending and receiving) antennas, but also in other parts of embedded systems (especially microcontrollers/microprocessors) – yet our focus was set on the communication aspects, and we disregarded all other energy consumers. Furthermore, we just touched on the topic of energy generation. Basically, we assumed that energy is either stored (in capacitors or batteries) or produced live according to the movement pattern of the sender. In both areas very interesting future research topics can be defined.
We are especially interested in the question of the “distribution of intelligence” in the network (i.e. should calculations be performed locally and their results be transmitted to a data base, or should just the raw data be transmitted and the calculation be performed centrally?). We consider that this topic has the potential for several years of research in future research projects. We have already made some effort in the application domain of ICT support for dynamic evacuation.
The challenge is to decentralise the intelligence of an evacuation support system for emergency cases (fire or gas in a building) in order to provide situational and personalised information for evacuees without overloading the network nodes. Besides energy aspects (in case of a breakdown of the regular power supply) one has to face real-time, safety and security aspects. Thus policies determining which data have to be transmitted when and where have to be defined (Hofmann et al., 2009).
Another research challenge is to define standards for open sensor/actuator systems for building automation. Our goal is the prototypical realisation of a generic in-house communication infrastructure providing a multi-user/multi-application approach, i.e. every registered user has access to sensor data (if allowed; also a billing system is possible here) and to applications that perform control tasks (e.g. remote heating/cooling). Similar solutions can be thought of also for traffic control. For instance a driver could access traffic data and plan/modify the route of the journey according to the collected sensor data.

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Mobile and Wireless Communications Physical Layer Development and Implementatiom

Edited by Salma Ait Fares and Fumiyuki Adachi

ISBN 978-953-307-043-8
Hard cover, 290 pages
Publisher InTech
Published online 01, January, 2010
Published in print edition January, 2010

Mobile and Wireless Communications have been one of the major revolutions of the late twentieth century. We are witnessing a very fast growth in these technologies where mobile and wireless communications have become so ubiquitous in our society and indispensable for our daily lives. The relentless demand for higher data rates with better quality of services to comply with state-of-the art applications has revolutionized the wireless communication field and led to the emergence of new technologies such as Bluetooth, WiFi, Wimax, Ultra wideband, OFDMA. Moreover, the market tendency confirms that this revolution is not ready to stop in the foreseen future. Mobile and wireless communications applications cover diverse areas including entertainment, industrialist, biomedical, medicine, safety and security, and others, which definitely are improving our daily life. Wireless communication network is a multidisciplinary field addressing different aspects raging from theoretical analysis, system architecture design, and hardware and software implementations. While different new applications are requiring higher data rates and better quality of service and prolonging the mobile battery life, new development and advanced research studies and systems and circuits designs are necessary to keep pace with the market requirements. This book covers the most advanced research and development topics in mobile and wireless communication networks. It is divided into two parts with a total of thirty-four stand-alone chapters covering various areas of wireless communications of special topics including: physical layer and network layer, access methods and scheduling, techniques and technologies, antenna and amplifier design, integrated circuit design, applications and systems. These chapters present advanced novel and cutting-edge results and development related to wireless communication offering the readers the opportunity to enrich their knowledge in specific topics as well as to explore the whole field of rapidly emerging mobile and wireless networks. We hope that this book will be useful for students, researchers and practitioners in their research studies.

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