UNIWERSYTET TECHNOLOGICZNO-PRZYRODNICZY
IM. JANA I JĘDRZEJA ŚNIADECKICH W BYDGOSZCZY
ZESZYTY NAUKOWE NR 261
TELEKOMUNIKACJA I ELEKTRONIKA 16 (2012), 17-25

TOWARD MORE EFFICIENT WIRELESS “LAST MILE” SMART GRID COMMUNICATION SYSTEMS

Piotr Kiedrowski[1], Gabriel A. Deak[2], Kevin Curran[2],
Joan Condell[2], Bozydar Dubalski[1]

[1]Institute of Telecommunication, University of Technology and Life Science
Kaliskiego 7, 85-789 Bydgoszcz, Poland
[2]ISRC – University of Ulster, Magee Campus, Northland Rd., BT48 7JL, Derry, UK

Summary: Multi-hop techniques are very popular in Wireless Sensor Networks as they are used to solve coverage problems. The drawback of these techniques is the low reliability. The aim of this paper is to outline hardware solutions that improve the efficiency of wireless networks intended for “last mile” smart grid communication systems. Typical Wireless Sensor Networks cannot take advantage of these solutions due to power constraints. Fast carrier detection and the probability of collisions, forward error correction, data whitening, and clear channel assessmentare discussed as hardware solution to improve wireless network efficiency for “last mile” smart grid communication systems. The hardware solutions significantly improve the efficiency of the wireless network intended for “last mile” smart grid communication systems.

Keywords: smart grid, wireless sensor network, last mile communication, PER vs. RSSI

1. INTRODUCTION

Successful implementation of Smart Grid (SG) solutions depend mostly on the adopted communication solutions [1]. Currently, the mainproblem in the implementation of Smart Grid communication systems is the solution of the "last mile", part of SG communication networks. This part of networks has a decisive impact on the cost of implementation and operation of the whole communication system. Thus very cheap sensor-based devices have been used to deploy “last mile” wireless networks. Wireless Sensor Networks (WSNs) use similar hardware solutions.

A typical node in a WSN consists of an antenna, a microcontroller, a transceiver and a sensor. In Europe, microwaves with frequencies 433 MHz and 868 MHz (ISM – Industrial, Scientific, Medical radio band) are very often used for automatic meter reading (AMR) systems and WSNs. Nodes using these frequencies have a maximum transmission power of approximately 10 dBm and a short transmission range. In order to increase the transmission range a multi-hop technique is often used. Thus a node in a network may act as a source node, destination node, or a transfer node. The only difference between typical WSN nodes and SG nodes is the power supply. WSN nodes are powered by small batteries whilst SG ones are powered directly from mains electricity monitored by this node. If there are no power constraints we can implement different system solutions e.g. communications protocols or topology control. System solutions are mainly realized by software methods. However, the best results in improving the efficiency of the network are obtained by using the software and hardware solutions simultaneously.

In this paper we have proposed four hardware solutions such as fast carrier detection, forward error correction, data whitening and clear channel assessment. The hardware solutions significantly improve the efficiency of the wireless network intended for “last mile” smart grid communication systems. These solutions cannot be applied in typical WSN where the nodes have power constraints.

2. FAST CARRIER DETECTING AND COLISSIONS PROBLEM

Using a multi-hop technique, the reliability of the path between source and destination nodes is based on individual reliability of all nodes in the path. The Packet Error Ratio (PER) value is high for communications between sensor-based devices compared to other types of communication media e.g. optical fiber.

Multi-hop techniques are very popular in WSN. These techniques solve the coverage problem. However wireless communications using these techniques have low reliability. A solution to cope with the high PER value is fairly easy to implement when we do not have to consider energy efficiency. A multipath routing protocol [2], using more than one path between source and destination nodes at the same time, could fix the problem. Multipath routing protocol is wasting more energy but this is not a problem in proposed application. However, generating many redundant transmissions still seems to be a problem. This can be evaluated as the probability of sending two or more packets at the same time, using the equation below:

$$P_C(k,T,t)=1-\frac{\left(\frac{T}{t}\right)\cdot\left(\frac{T}{t}-1\right)\cdot\ldots\cdot\left(\frac{T}{t}-k+1\right)}{\left(\frac{T}{t}\right)^k} \tag{1}$$

where:

- k is the number of nodes in a cluster, transferring a packet in a defined hop,
- t shows how long the CD (Carrier Detect) status cannot be monitored,
- T is a maximum value of random time delay in the process of packet reliability.

The value of P_c could be decreased by increasing the value of T if there was no influence on the communication time. Similarly, P_c could be decreased by decreasing the value of k, but we have no influence on the network topology. The only possibility to decrease the value of P_c is to reduce the time t. Fig. 1 presents the probability of collisions for three values of t based on the number of nodes k.

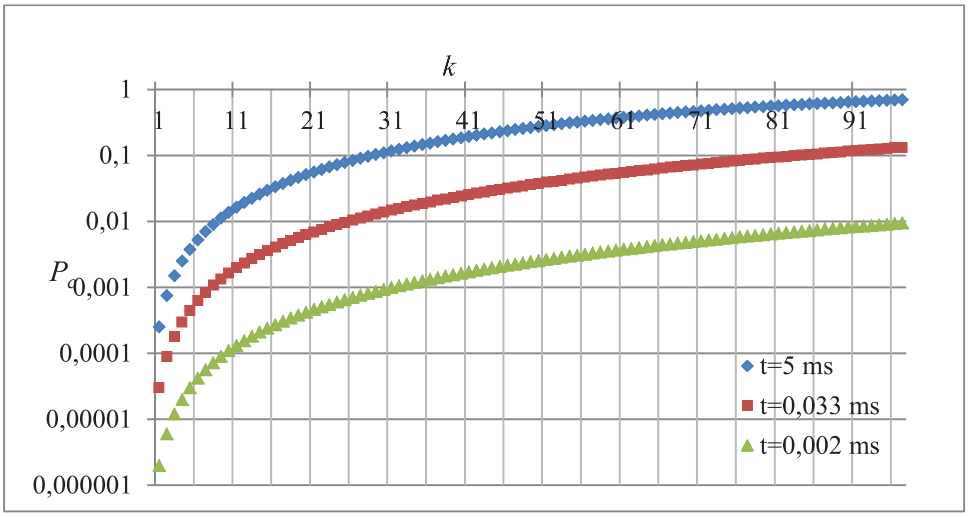

Fig. 1. Probability of collisions vs. the number of nodes in transferring cluster

Equation 1 was used to obtain the results in Figure 1 for a constant value of T equal to 1 s. The value of t is the time needed to detect status of carrier (if channel is busy or free). Usually radio modules have clocks factory set only to 32 kHz. This is because radio modules are mainly intended to work in WSNs, where the power conservation is the main issue. In this case, when clock is slow, the time needed to detect CS is long e.g. 5 ms if it is readout via SPI (Serial Peripheral Interface). When the same module is overclocked up to 5 MHz the information about CS is achievable in about 33 μs. The last example, which is also presented in Fig. 1, concerns the same module with both the overclocked microcontroller and additionally with the CD output pin of the transceiver connected directly to the IRQ input pin of the microcontroller. With such modifications t=2 μs. Assuming that the probability of a collision cannot be greater than 0.01, the maximum number of nodes transferring the same packets should not exceed 9 if hardware solutions allow microcontrollers to detect a carrier with sense of 5 ms. The main reason of using the 0.01 threshold value is the fact that many applications use this value as the unreliability measure in order to calculate threshold parameters. In [3] the value PER=$10^{-2}$was obtained using this threshold value as the probability of collision. This time is too short considering that 9 nodes or bigger clusters occur very often. By using a module with an overclocked microcontroller, we can detect carrier faster. In this case we have the possibility to obtain a probability of collision less than 0.01 if the size of transferring cluster is smaller than 27 nodes. The case when the number of nodes in a cluster is greater than 27 is rare. The whole subnet (managed by one sink) contains at most a few hundred nodes spread over a large area. Thus, it can be concluded that in this case, when the network is merely energy meters, using an overclocked radio module is sufficient when multi-hop and multipath transmission technique are used. In the futureif SG systems usagewill increase then the number of nodes in the network will increase several times. In this case, the third solution will be necessary to ensure a low probability of collisions in clusters consisting of more than one hundred nodes.

3. HARDWARE FORWARD ERROR CORRECTION

Most of the one-chip transceivers on the market have built in support for forward error correction (FEC). By using this option the energy consumption increases. This is the main reason why FEC is not a very popular technique for improving the transmission parameters in typical WSN solutions. FEC is a good choice when energy efficiency is not a concern.

In order to see if this option improves the efficiency of transmission we ran an experiment where we alternate sending and receiving packets on the network – odd packets with FEC, even without FEC.

The efficiency of transmission can be assessed by various methods. The most popular methods are the quality of service assessment and the reliability of links measurement. The quality of service method is a direct method and is dedicated to specific solutions e.g. implemented communication scheme. The second method is more general and estimates the quality of service when the implemented solutions are known. The efficiency of transmission with FEC was assessed using these two methods.

As a measure of the quality of service we have considered the data collection speed (number of readings from nodes per time interval) for all the nodes in our test network. The speed increased with 9% using FEC compared to the case when FEC was off.

We have also measured the PER versus Received Signal Strength Indicator (RSSI) in the neighbourhood of the sink, based on all data received by the sink. We cannot plot both PER_{FEC}(RSSI) and PER_{noFEC}(RSSI) in the same graphicas curves overlap. During long-term tests the results were always better using FEC compared to the case without FEC. The global values of PER (regardless of RSSI) were as follow: $PER_{FEC} = 9.92 \cdot 10^{-2}$and $PER_{noFEC} = 1.08 \cdot 10^{-1}$.

We expected that the use of FEC would improve the transmission. However the difference compared to the case without FEC was not large enough to help us assess the transmission based on PER. Such a situation is the effect of the implemented communication scheme on the function of the relative PER growth versus RSSI, expressed by the following equation:

$$\delta PER_{noFEC,FEC}(RSSI) = \frac{PER_{noFEC}(RSSI) - PER_{FEC}(RSSI)}{PER_{FEC}(RSSI)} = \frac{PER_{noFEC}(RSSI)}{PER_{FEC}(RSSI)} - 1 \quad (2)$$

Figure 2, obtained using (2), shows the influence of FEC on the transmission reliability.

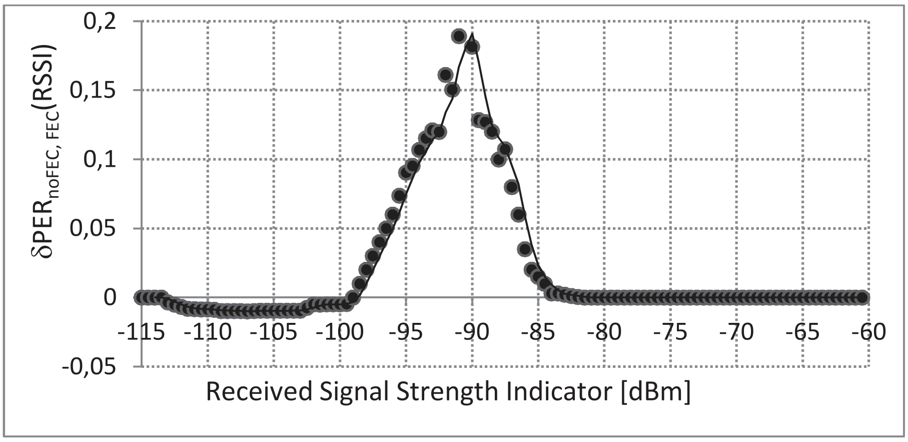

Fig. 2. The influence of FEC on the transmission reliability – relative PER versus RSSI

Four power ranges can be distinguished analysing the data in Fig. 2. The first power range is for RSSI values less than -113 dBm. In this range all packets have errors with or without using FEC.

The second power range is for RSSI values between -113 dBm and -99 dBm. In this range the value of the relative PER is less than zero.This means the FEC function does not improve transmission but worsens it instead. This situation can be easily explained taking into account the range of RSSI. The signal received by a sink is very weak which means the nodes are located on the edge of their radio range. When the FEC is switched off, nodes located on the edge do not receive packets from the sink or receive packets with errors, thus do not send copies. However, when the FEC is switched on, some nodes receive error free packets from the sink and send copies to other nodes. This improves the communication but does not improve the relative PER measured at the sink point.

The third power range is for RSSI values between -99 dBm and -82 dBm. In this range the value of the relative PER is greater than zero and it goes up to nearly 20% for -90 dBm, thus the FEC function improves transmission.

The fourth power range is for RSSI values greater than -82 dBm. In this range all packets are error free and do not depend on the status of the FEC function.

Concluding, we can say that only in the power range between -99 dBm and -82 dBm is the FEC function significantly effective. We can also say that in the power range between -113 dBm and -99 dBm, FEC is only seemingly in effective. In other power ranges FEC function does not affect the PER. Nevertheless, the FEC function can be very useful under conditions of interferences especially in the fourth power range. This phenomenon was explained based on the observations presented in [4].

4. DATA WHITENING

In the ideal case, over many different types of media, random DC-free (Direct Current) data is transmitted. In many cases the data transmitted contains long sequences of ones and/or zeros. Performance can then be improved by whitening the data (DW) before transmitting and de-whitening at reception.

The data is prepared by applying exclusive-or (XOR) with a pseudo-random sequence before transmission. Results in this paper were obtained using pseudo-random bit sequences generated by the polynomial function $G(x)=x^9+x^5+1$. This method is called data whitening. When the data is received, it is XOR'd with the same pseudo-random sequence to obtain the original data. Fig. 3 presents a circuit for data whitening:

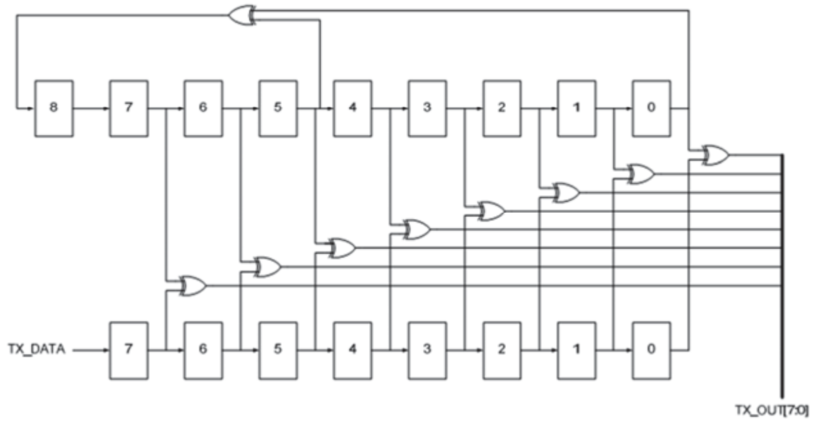

Fig. 3. Data whitening circuitry [5]

Figure 3 shows a circuit for data whitening similar to the scrambler circuit implemented in SONET/SDH optical communication technology to realize the same function as a line coding i.e. avoiding of long sequences of zeros or ones.

Using a similar technique as in the examination of the FEC, i.e. alternate sending and receiving packets we have analysed the improvement on the transmission efficiency by alternating the usage of DW with the case when DW is not used. However the DW function had no effect on the transmission efficiency, either on readings speed or PER

One should not consider our results as general due to the specific telemetric data organized in packets. The packets, which carried telemetric data, consist of the overhead and the data field. The data fields are encrypted so they are already random and do not need to be whitened. The overhead consist mostly of long addresses which rarely contain long sequences of zeros and never contain long sequences of ones, where an address is a real serial number of adevice coded in BCD.

5. CLEAR CHANNEL ASSESSMENT

The Clear Channel Assessment (CCA) is used to indicate if the channel is free or busy, during the transmitting process. There are different criteria for determining whether the channel is free or busy such as: RSSI is below threshold, receiver currently is receiving a packet etc.

The CCA function is very useful if the point-to-point transmission mode is used with a half-duplex transmission channel. The CCA function can be also useful when we use not advanced routing protocols e.g. flooding [6] or gossip [7], whilst when we use advanced routing protocols e.g. energy greedy quasi-flooding (EGQF) routing protocol [8], which is used in our test network, the usage of the CCA is not recommended.

This is because, even though, during the transmitting process with CCA enabled, the receiver is in RX state, it cannot receive any packet but just wait for an opportunity to transmit the own, hold in TX buffer, packet as soon as channel is free. Using advanced transmission techniques, the information which is waiting to be sent can be out-of-dated by received one. So, we recommend using the CCA feature only for a simple e.g. ping-pong transmission systems in order to shorten the time of an idle state required between receiving and transmitting states.

Examining the CCA in our test network, the CCA function had no effect on the transmission efficiency but had a negative effect of increasing the average rate of transmitted packets per query.

CONCLUSIONS

Most of the single chip transceivers have many internal modules which can be programmatically switched on or off. However the drawback of using additional modules is increased power consumption, therefore developers often have to opt out of using additional/optional possibilities offered by modern communication chips.

In the case of systems with no energy deficit (e.g. SG) one can use other solutions, both hardware and software. Here, however, the risk is that the designers decide to include all internal modules aimed at improving the transmission parameters. The article shows that by deciding to include any additional function, one has to take into account not only energy consumption but also the protocols used by the systemsuch ascommunication protocols.

Transmission parameters and quality of service were compared for two cases, the first with optional functions enabled and the second with optional functions disabled. Comparison of transmission parameters and quality of service with all features enabled or disabled is not presented. Such an experiment was not performed, because a solution that has the greatest impact on transmission parameters and network performance is a fast carrier sensing. Other functions have a significant effect only when the CS detection is not fast enough. Therefore a fast carrier detecting solution is the most important and must be taken into account at the stage of hardware design. Usage of other solutions depends strongly on the system to be implemented and the characteristics of this system should be considered before switching on optional features.

BIBLIOGRAPHY

[1] IEEE SmartGridComm 2011 Concludes, Successful 2nd Annual Event in Brussels, Belgium, IEEE Communications Magazine, Conference Report, December 2011, pp. 18-19.

[2] Al-Karaki A.N., Kamal A.E., Routing Techniques in Wireless Sensor Networks: a Survey, IEEE Wireless Comm., Dec. 2004 (2004), 6-28.

[3] Texas Instruments (2006) CC1100 Single Chip Low cost Low Power RF Transceiver. Texas Instruments Incorporated, 89-90.

[4] Boryna B., Dubalski B., Kiedrowski P. and Zabłudowski A.: Image Processing and Communications Challenges 2 (ed. Ryszard S. Choraś), Errors Nature in Indoors Low Power 433 MHz Wireless Network, 2010 Springer Verlag, Advances in Intelligent and Soft Computing 84, pp. 373-378.

[5] Grant Christiansen: Data Whitening and Random TX Mode, Texas Instruments, 2010.

[6] Durresi A., Paruchuri V.K., Iyengar S.S., Kannan R.: Optimized Broadcast Protocol for Sensor Networks, IEEE Transactions on Computers, Vol. 54, No. 8, August 2005, pp. 1013-1024.

[7] Boyd S.,Ghosh A., Prabhakar B., Shah D.: Randomized Gossip Algorithms, IEEE Transactions on Information Theory, Vol. 52, No. 6, June 2006, pp. 2508-2530.

[8] Kiedrowski P., Dubalski B., Marciniak T., Riaz T. and Gutierrez J.: Image Processing and Communications Challenges 3 (ed. Ryszard S. Choraś), Energy Greedy Protocol Suite for Smart Grid Communication Systems Based on Short Range Devices, 2011 Springer Verlag, Advances in Intelligent and Soft Computing 102, pp. 493-502.

KU BARDZIEJ WYDAJNYM SIECIOM BEZPRZEWODOWYM "OSTATNIEJ MILI" PRZEZ INTELIGENTNE SYSTEMY KOMUNIKACJI W SIECI

Streszczenie

Technika transmisji multi-hop jest powszechnie stosowana w bezprzewodowych sieciach sensorowych w celu powiększenia zasięgu jej działania. Jednak wadą techniki multi-hop jest duża zawodność transmisji. Celem artykułu jest przedstawienie sprzętowych metod poprawy jakości transmisji w bezprzewodowych sieciach sensorycznych przeznaczonych do obsługi komunikacji w systemach Smart Grid w obszarze ostatniej mili. Prezentowane w pracy metody nie są stosowane w klasycznych bezprzewodowych sieciach sensorowych ze względu na deficyt energii charakterystyczny dla sieci, których węzły zasilane są bateryjnie. Prezentowane metody oraz ich skuteczność dotyczą takich zagadnień, realizowanych metodami sprzętowymi, jak: szybkie wykrywanie sygnału nośnej, korekcja błędów wprzód, uprzypadkawianie strumienia danych, kryterium decyzji o transmisji CCA (ang. clear channel assessment). W pracy w sposób teoretyczny i praktyczny wykazano skuteczność proponowanych metod.

Słowa kluczowe: sieci Smart Grid, sieci sensorowe, komunikacja ostatniej mili, PER vs RSSI