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MEDIA INDEPENDENT PROTOCOL SUITE FOR ENERGY MANAGEMENT SYSTEMS BASED ON SHORT RANGE DEVICES

ABSTRACT *This paper presents a new routing protocol which is dedicated for Smart Grid communication solution. This protocol is an adaptation of the flooding protocol, which was needed to work in the point-to-point transmission mode. The presented protocol is intended for the same hardware solution as in sensor networks but with a different approach to the energy efficiency, it is why this protocol was called energy greedy quasi-flooding. The presented protocol can be used in the communication network independently from a media type.*

Keywords: *Energy Management, Sensor Networks, Smart Grid*

1. INTRODUCTION

Among the various types of energy, such as: electricity, fuel, steam, heat, compressed air and other like media, electricity energy is the easiest to monitor [1, 2] and also it is the easiest to manage according to requirements of EN 16001 Energy management systems (EMS) [3].

The communication protocol which is presented in this work is independent from communication media types and is mainly intended for PLC (Power Line

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Communication), UHF wireless and even IrDA (Infrared Data Association) transmission techniques.

The success of implementing the electricity EMS depends on the cost of the most common devices in the network i.e. communication nodes, which work autonomously or are installed in energy meters, power guards or smart terminals etc. The cheapest hardware solutions are the solutions used in sensor networks, mainly in wireless sensor networks (WSNs). It is also important to minimize operating costs of the communication system. They can be minimized by using ISM (Industrial, Scientific and Medicine) bands for radio transmission and bands under 100 kHz frequency (telemetry bands) for PLC transmission. These bands have limitations of the maximum emission of power. Thus, as in WSNs to enlarge the communication area the multi-hop technique is applied.

So far, the similarities to WSNs were shown, but there are also some differences, such as: RAM memory deficit as a result of data encryption and no limitations in power consumption of nodes. These two differences give us a completely new approach to protocol problems, intended for communication systems based on short range devices (SRDs).

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2. PROBLEMS WITH THE MULTI-HOP COMMUNICATIONS TECHNIQUE

If the source and destination nodes are out of range, they have to use other nodes to relay the information packets. In such a case the path between source and destination nodes is set with using more than one link (or hop), which is called the multi-hop technique. The reliability of the path between source and destination nodes is the result of individual reliabilities of all the links used in establishing a path. The reliability metrics is the packet error rate (PER).

Knowing the PER of all the links in the path, the PER of the path can be calculated using the following formula:

$$PER = 1 - \prod_{h=1}^{H} \left(1 - per_h\right) \tag{1}$$

where: H is the number of hops in the path and per_h is PER of a link in the h-th hop.

Using the SRD for communication the value of PER is high, compared to other types of communication media e.g. optical fibers. Papers evaluate radio propagation with sensor-network style radios [4, 5, 6] observed in their experiments where over 10% links are asymmetric and a third of links have PER greater than $3 \cdot 10^{-1}$. I found similar results and some even worse i.e. over 25% links in the vicinity of the base station (BS) are asymmetric – the receiving range of BS is greater than the transmitting one. In such conditions and taking into account (1), PER in a path is very high, what shows the example in Figure 1.

Implementation of multi-hop technique solves the coverage problem, when SRDs are used, but it also generates three new problems:

1. How to choose the links to get a reliable path?
2. How to establish a path?
3. How to increase the reliability of communication between the BS and the other nodes?

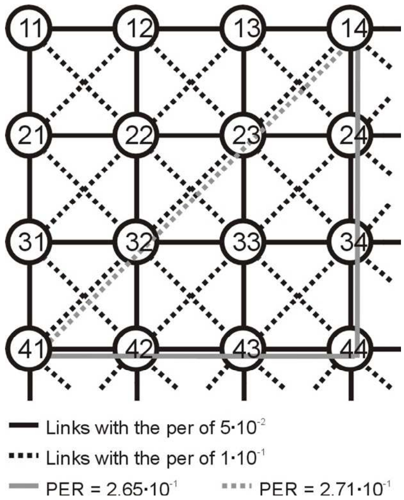

Fig. 1. An Example Fragment of the Sensor Network

The solution of the third problem is fairly easy, especially when the energy efficiency problem does not exist; this solution is a multi-path routing protocol [7] i.e. using more than one path between source and destination nodes at the same time.

3. MULTI-PATH ROUTING PROTOCOLS

Multi-path scheme is useful for delivering data in unreliable environments such as presented in this work. It is easy to prove that network reliability can be increased by providing several path between source and destination nodes and sending the same information via each path.

The unreliability of communication by means of a multi-path scheme is the product of the PER of individual paths, and knowing the PER of links can be calculated using the following formula:

$$PER_{multipath} = \prod_{n=1}^{N} PER_n = \prod_{n=1}^{N} \left(1 - \prod_{h=1}^{H_n} (1 - per_h) \right) \quad (2)$$

where: N is the number of paths, other variables were already explained in (1).

Using the example from Figure 1 and (2), the unreliability of connection between nodes 14 and 41 equals to $2.65 \cdot 10^{-1} \cdot 2.71 \cdot 10^{-1} \cong 7.2 \cdot 10^{-2}$, if the presented two paths are used. Using the same example, but assuming there are three paths: two shown in Figure 1 and the third set via nodes: 13, 12, 11, 21 and 31 the value of unreliability will be $2.65 \cdot 10^{-1} \cdot 2.71 \cdot 10^{-1} \cdot 2.65 \cdot 10^{-1} \cong 1.9 \cdot 10^{-2}$, which is almost three times better than a PER of the best link in the network.

In the above examples separated paths were always used, it is obviously possible that different paths can partially use the same links. There are many kinds of multi-path routing protocols [7] as result of a trade-off between the energy efficiency and the reliability of the communication.

This section solved the problem of increasing the reliability of communication. The way the third problem (pointed in the previous section) was solved causes that the first problem is no longer valid but the second problems is still unresolved. Taking into account the specificities of the presented network application, characterized by memory deficits and no energy restrictions, it is possible to use a conventional flooding routing protocol. Flooding routing protocol wastes energy and bandwidth when sending extra and unnecessary copies of data by sensors covering overlapping areas [7] but does not need paths establishing, therefore implementation of a flooding routing protocol solves the second problem.

4. FLOODING ROUTING PROTOCOL

As it was already said – flooding routing protocol wastes energy which is not a problem in presented application of WSNs, but wasting of bandwidth is still a problem because it generates many redundant transmissions, which may cause a serious broadcast storm problem [8]. Presented in this work the media independent protocol is an adoption of flooding routing protocol by changing its main paradigm i.e. instead of coping every message once by every node, messages are copied only if it is necessary (from the point of view of the node).This solution might be called an energy greedy quasi-flooding (EGQF) routing protocol for point-to-point communication, as it will be shown later, as an approach, which reduces redundant transmissions.

Both flooding protocol and EGQF protocol relay packet (send copy of it) after a random period.

5. ADAPTATION OF THE FLOODING ROUTING PROTOCOL

Generally, the adaptation consists in facts that packets are copied only if it is necessary and that broadcasting process may be broken.

Energy greedy quasi-flooding protocol has three types of messages, those are: COMMAND, RESPONSE and ACK/CANCEL. In most cases the traffic is forced and co-ordinated by the BS, which queries a node using the COMMAND message, the node responses to the BS using RESPONSE message, at the end BS sends ACK/CANCEL, which acts as an acknowledgement for destination node or cancels transferring process in the remaining nodes. If the traffic is forced by the node, only COMMAND and RESPONSE packets are used.

Different than the typical flooding protocol, in EGQF protocol massages are copied only if the transfer discriminator (TD) value of massage is greater than a previous stored one. Initial (or set at the end of the process) the transfer discriminator value is zero. The transfer discriminator consists of three fields organized in the following order: the priority bit, the packet type code and the time to live (TTL) counter.

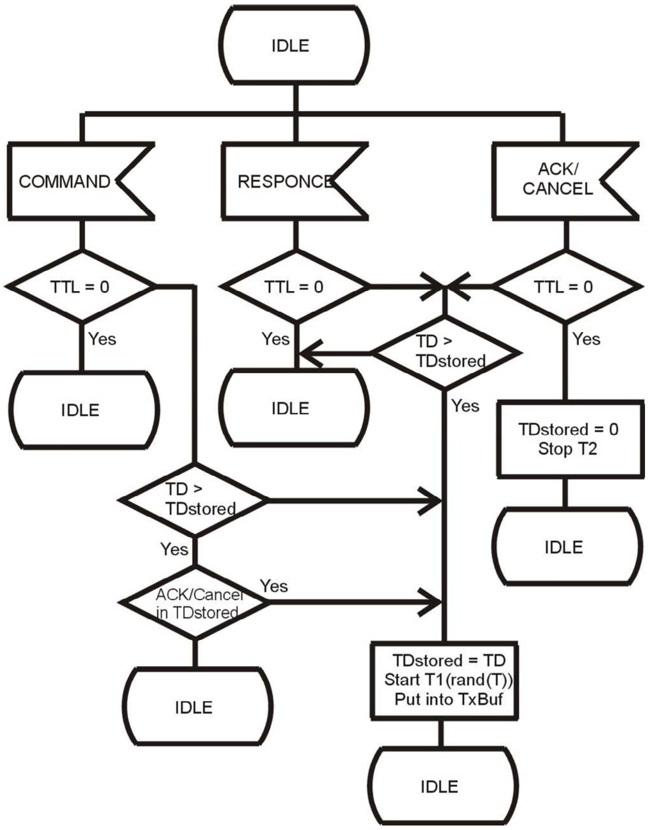

Fig. 2. A fragment of EGQF routing protocol algorithm

During the normal operating, the priority bit is set to zero. The packet type code has the value of: zero for COMMAND, one for RESPONSE and two for ACK/CANCEL. Values of TTL are decremented by nodes during the transfer process. Therefore intermediate nodes might change only the TTL field. If a maximum number of hops for the packet is reached (TTL equals zero), packet is not transferred further.

These are also explained using the Figure 2, which shows us a fragment of the EGQF routing protocol algorithm in SDL (Sequence Diagram Language) format according to [9].

Analyzing this fragment of the algorithm, it is easy to notice that each packet type is handled differently and also that messages: are copied once, are not copied or are copied more than once. When packets are not copied without the need, emission reduction benefits are obvious. The benefit of copying the packet more than once is explained in figure 3, which presents examples of a simple sensor network having implemented different routing protocols. Figure 3 presents the special case when a packet to the node E arrived earlier from the node D than from the node B.

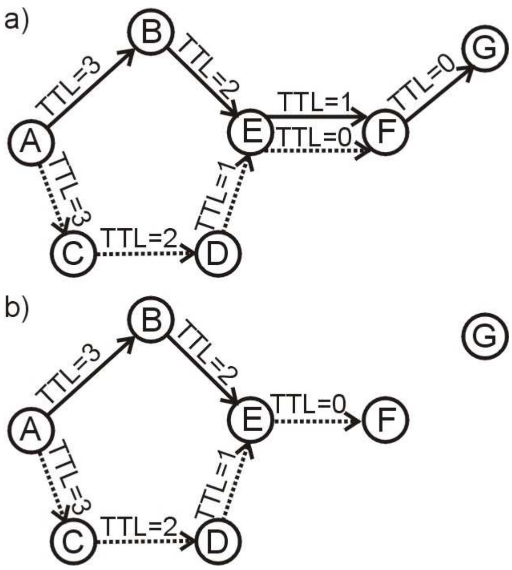

Fig. 3. The special case when a packet arrived earlier to the node E via nodes C and D: a) using EGQF protocol, b) using flooding protocol

As it is shown in Figure 3a, connection between nodes A and G can be realized by two traces: via the node B, and via nodes C and D; taking into account, the initial value of TTL, only the trace via the B-node is effective. In turn, the Figure 3b shows what would happen if proposed solutions were not implemented – simply a node G would be sometimes unreachable.

The probability value of sending a copy of the packet more than once is generally small and depends on network topology. Additionally, it is possible to calculate the value of this probability for a given topology.

Using a uniform distribution to generate random time delay, the probability of drawing a value between 0 and t is t/T, where T is the maximum value that can be generated. Knowing that the described case can be mathematically shown as $t_C + t_D < t_B$, the maximum value of this conditional probability is always less than the extreme of the following quadratic functions: $-x^2 + t_B x$. For example if node B sends a copy of the packet after $t_B = 0{,}5T$, the probability that the packet arrived earlier via C and D nodes is less than 0.0625.

6. RETRANSMISSION IN EGQF PROTOCOL

Generally, it is not necessary to use any retransmission technique [4] if a multi-path technique in the broadcast transmission mode is used. EGQF protocol is intended for operation in a point-to-point bidirectional communication mode. COMMAND type packets arrive to the destination node at different times, using different paths. After receiving the first COMMAND, the destination node sends a RESPONSE, if the channel is free. It is quite possible that this RESPOSE packet may be disturbed by other nodes located in the vicinity of a destination node, which still send copies of COMMAND packets. This would be a bottleneck of the EGQF protocol.

To avoid such a situation, the retransmission mechanism was implemented in the EGQF protocol. The retransmission mechanism is used only by the destination node, without of any extra RAM memory occupation, because the RESPONSE packet is already kept in the transmission buffer of a transceiver. The decision to launch the retransmission is as follows: after sending the RESPONSE, the destination node starts a retransmission timer. After the duration of $T + T_V$ (where T_V is the virtual time [10]) the retransmission timer expiries and the destination node sends RESPONSE again and stops the timer. This timer can be also stopped, if a copy of RESPONSE or ACK/CANCEL will be listened during the $T + T_V$ period. The number of retransmissions is reduced by a protocol parameter – RC (Retransmission Counter) [9]. Testing the network which consists of 40 nodes with RC parameter set to 1 showed that the reliability communication coefficient increased from 90 to 99.8%, so the testing with RC greater than 1 does not make sense, for three additional reasons:

- the unreliability is not only caused by disturbances in the vicinity of a destination node;
- the probability of further disturbances decreases after every $T + T_V$ period;
- sometimes, it is better to cancel the process and starts from the beginning than waits.

This test showed two ways of an implementation of the retransmission mechanism: with hardcoded RC set to 1 and with RC treated as a protocol parameter, where RC set to 0 means that retransmission function is not used by the destination node.

7. COMPARISON EGQF PROTOCOL TO FLOODING PROTOCOL

The EGQF routing protocol was designed for point-to-point communication whilst flooding protocol is used for broadcast communication. Therefore these two protocols should not be rather compared. Presented comparison is to show what an adaptation gave, regarding the use of the flooding protocol for communication in point-to-point mode.

The first advantage is that the EGQF protocol allows network to operate on slightly wider range than the flooding one, using the same initial value of TTL, what was already explained in Figure 3.

The second advantage is the emissivity of EGQF, which is less than the emissivity of flooding protocol. Researchers who deal with WSNs very often formulate this problem as an energy efficient communication because there is a direct relationship between the emissivity and power consumption. They use various methods to measure or describe it, such as: a lifetime, relations between a distance and number of sending bits or energy per bit ratio [11]. To describe the emissivity is best to use the parameter – E, which is the quotient of the number of sending packets, and the numbers of nodes in the network, so if E is the smaller the better. Assuming that the network consists of n nodes and one BS, the E parameter equals to 1, if the flooding protocol is used. Using the EGQF protocol E can theoretically (with very low probability) be greater than 1, but practically it is always less than 1. This fact is best explained analytically, for the four cases:

- COMMAND and RESPONSE packets are never copied when BS communicates with neighboring nodes, because of implementation of the T_V timer;
- the reception of a RESPONSE packet replaces the process of COMMAND relaying by the process of RESPONSE relaying;
- the reception of a ACK/CANCEL packet replaces both the process of COMMAND relaying or the process of RESPONSE relaying by the process of ACK/CANCEL relaying;
- the reception of a COMMAND packet replaces the process of ACK/ /CANCEL relaying by the process of COMMAND relaying.

The last advantage is the communication speed. Using the flooding protocol the time between next queries is equal to the double product of the maximum number of hops and T value, whilst using EGQF protocol time between next queries depends on the location of nodes in the network and its topology. For every node, the time between next queries can be calculated using the following formula:

$$T_{between\_queries} = T + 2hT_V + T\sum_{i=1}^{h}\frac{1}{c_i+1} + T\sum_{i=1}^{h}\frac{1}{r_i+1} \tag{3}$$

where: h is a distance expressed in number of hops from node to the BS, c is size of the cluster of nodes i-hops away from BS able to transfer COMMAND packet and r is size of the cluster of nodes i-hops away from BS able to transfer RESPONSE packet, T and T_V were defined earlier.

The analysis (3) shows that the EGQF protocol has an advantage over the flooding protocol especially when the network is dense and wide (has many hops). For example, using the flooding protocol in one-hop network the $T_{between\_queries} = 2T$ but using EGQF in the same network in the worse case $T_{between\_queries} = 2T + 2T_V$. Taking into account that the value of T_V is at least ten times smaller than value of T, the EGQF protocol is not much worse than the flooding one. Knowing that these protocols are intended to work in multi-hop networks consisting of many hops, the EGQF protocol will always be better.

8. CONCLUSION

This paper showed that the simply adaptation of the flooding protocol enabled to develop a new EGQF protocol, which uses all the advantages of flooding one and eliminates all its disadvantages. The process of adaptation might be extended further using many tricks, e.g.:

- use of information about the distance from the BS to a node to adjust the initial value of TTL what allows to reduce the emissivity,
- use of information about number of neighbors to decrease T value in nodes what allows to increase the communication speed.

This year, the EGQF protocol has been implemented in the distributed telemetric system based on electricity energy consumption meters (EECM). With exception of communication features, this type of EECM was already described in [12].

There is no evidence to suggest that such solutions could not be also applied to EMSs based on the inexpensive SRDs.

How much better is the EGQF protocol regarding the flooding one can be determined by methods described in [13]. It is very useful to implement the EGQF and flooding protocols together, for a point-to-point communication and for a point-to-multipoint communication, respectively. The implementation of these protocols takes only 16 kB of RAM memory, what is a good result regarding the problem of RAM memory deficit. Additionally, the proposed solution is not only independent of the type of the communication media but it also suites smart grid technologies based on hybrid networks e. g. PLC together with microwaves. In the same way, the presented approach to WSN problems intended for communication systems based on SRDs complements the solutions presented in [14] because the EGQF protocol gives us an independence from network topologies and also allows the same node to act either as a terminal or as a repeater.

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NIEZALEŻNY OD MEDIUM PROTOKÓŁ DO ZASTOSOWANIA W SYSTEMACH ZARZĄDZANIA ENERGIĄ OPARTYCH NA NADAWCZO-ODBIORCZYCH UKŁADACH KRÓTKIEGO ZASIĘGU

Piotr KIEDROWSKI

STRESZCZENIE *W pracy przedstawiono nowy protokół routingowy, przeznaczony do komunikacji w systemach Smart Grid. Protokół jest adaptacją protokołu rozpływowego dla potrzeb komunikacji w trybie transmisji punkt-punkt. Protokół może pracować w sieciach opartych o te same rozwiązania sprzętowe, co w sieciach sensorowych, lecz w innych warunkach zużycia energii; to powód, dlaczego ten protokół został nazwany energetycznie zachłannym. Przedstawiony protokół może być wykorzystywany niezależnie od rodzaju medium transmisyjnego.*

Słowa kluczowe: *sieci sensorowe, Smart Grid, zarządzanie energią*