

MAC Layer Dynamic Backoff Scheme for Message Delivery Reliability in Wireless Sensor Networks

Ahmed Badi, Imad Mahgoub, Mohammad Ilyas
Computer Science and Engineering Department
Florida Atlantic University
Boca Raton, Florida, USA
{imad, mohammad}@cse.fau.edu

Abstract—We propose using dynamic backoff on CSMA-type MAC layer protocols to improve message delivery reliability in wireless sensor networks. It is assumed that the MAC layer is able to determine message reliability requirements by reading a reliability data bit embedded within the message. The basic concept is to apply shorter random backoff times to important messages. This gives them the opportunity to test the availability of the communication channel more frequently, enhancing their chance of finding the medium idle. However, this technique might produce the opposite result by allowing the MAC layer to retry sending the important messages in a higher frequency. As a result important messages may reach their maximum retry limit, and get removed from the network. To counteract, we also propose giving the messages a maximum retry limit based on their type. In this setting, important messages will have a higher maximum retry limit. We developed a simulation program to validate our proposed dynamic backoff scheme. The results obtained show that under reasonable network utilization level, the latency is reduced for important messages. Under heavy network utilization conditions, the dynamic backoff scheme drops normal messages leaving the network resources available to handle the delivery of important messages.

Keywords: MAC layer, Wireless Sensor Networks, Message delivery reliability, MAC backoff timer, simulation.

I. INTRODUCTION

Wireless sensor networks (WSNs) provide a new interface between the computational and physical worlds. They are among the fastest developing new technologies [1][2][3]. Researchers in academia, as well as several hardware and software companies are currently active on the development of these micro sensor devices and associated technologies. This field is at the frontier of networking

technology market. The availability of small, cheap low power embedded processors, radio transceivers and sensors, often integrated on a single chip is leading to the use of sensing, computing and wireless communications for monitoring and interacting with the physical world. These wireless sensor devices, also known as *nodes*, are assembled of the hardware components mentioned above, an energy source, in most cases battery together with networking and application firmware and software. Depending on the size of the network and the complexity required of each sensor, the cost of sensor devices can vary from hundreds of dollars to a few dollars. The size of a single sensor node can also vary.

In Wireless communication networks, CSMA MAC layer protocols use random backoff timer techniques. These techniques are used to address the issue of coordinating channel access. They proved to be effective in controlling channel access and reducing collisions and the need for retransmissions. CSMA MAC protocols use static schemes to calculate the backoff time applied to messages when the channel is busy. In the calculation of these backoffs, there are no provisions for the concept of message delivery reliability requirements or the concept of different message types in general. However, it can be argued that in communication networks, not all messages carry the same urgency or importance. As an example, in wireless sensor networks, a message notifying the operator of a critical system condition that needs to be acted upon to avoid failures is intuitively more important than a message only reporting normal operating parameters of the system. When network bandwidth is heavily utilized, messages will start to queue in intermediate nodes buffers. As some buffers get full, the network may start dropping messages without differentiating between important and regular messages. This possible loss of critical data will have a negative impact on the overall system's reliability.

As the wireless sensor networks research matures, it needs to move beyond studies that are focused on realizing these networks, e.g. studies that address the challenges of coverage, deployment, energy conservation and resource

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constraints. To build trust in using these systems, more emphasis should be placed on studying and analyzing the reliability and dependability of WSNs. So far, wireless sensor networks energy efficiency research has not taken reliability into consideration as a performance parameter or as a design constraint. The research in reliability for wireless sensor networks is relatively new. Each study on WSNs has defined reliability in line with their approach. In Section 2, we cover some of Wireless Sensor Networks reliability studies.

A. CSMA MAC and dynamic backoff

In the OSI network communication model, the communication process between two points in a network is divided into seven layers: Application, Presentation, Session, Transport, Network, Medium Access Control (MAC), and Physical layers [4]. The MAC layer regulates the usage of the shared communication medium. The MAC layer is also ultimately responsible for per hop transmission between neighboring nodes. Before transmitting frames a station must first gain access to the medium. For a Local Area Network (LAN) this can be the token in a token ring network. In a wireless network scenario the medium is the radio channel that all the stations share.

An important aspect of CSMA MAC protocols that is implemented by the distributed coordination function (DCF) is a random back off timer that a station uses if it detects a busy medium. If the channel is in use, the station must wait a random period of time before attempting to access the medium again. This ensures that multiple stations wanting to send data don't transmit at the same time. The random delay causes stations to wait for different periods of time and prevents them from sensing the medium at exactly the same time, finding the channel idle, transmitting, and colliding with each other. The back off timer significantly reduces the number of collisions and corresponding retransmissions especially when the number of active users increases.

The rest of this paper is organized as follows, in Section 2, we cover some relevant work in wireless sensor networks reliability. In Section 3, we outline our proposed dynamic backoff algorithm. Performance evaluation is presented in Section 4 along with simulation results. Section 5 concludes the paper.

II. RELATED WORK

Research in reliability for wireless sensor networks is relatively new. Each study on WSNs has defined reliability in line with their approach. One way to measure

reliability is to specify a 'data delivery probability' [5]. This measure is proportional to the energy cost, the higher the data delivery probability the higher is the energy cost. This fact of energy cost applied to all measures of reliability. Different types of data streams within the same network may require different reliability measures [5] e.g. reliability for single packet delivery as in the case of delivering aggregated data to the sink vs. block of data delivery reliability as in the case of code update, vs. periodic reports data reliability.

Several factors can affect the wireless medium data delivery reliability. Packet loss due to congestion was identified and studied as a factor affecting the transport layer data delivery reliability in [6]. Therefore, congestion control is considered critical to data delivery reliability. Other reliability studies consider link failure due to radio frequency interferences and packet collisions as the main factor affecting data delivery reliability [7][8][9][10][11]. Based on how reliability is defined, different solutions and techniques to improving the wireless link reliability were proposed. These techniques include sending the data message through multiple routes [11], using Erasure codes to add redundancy to the data packets [11], using MAC layer retransmissions [8][12], using MAC layer ACK/NACK control messages [13], dynamically adjusting the transmission power based on the channel noise conditions [14][15], or using a mixture of the mentioned techniques in a cross-layer fashion [16][17][18].

A. Wireless Sensor Networks Reliability Techniques

From the WSNs reliable protocols literature, some of the proposed techniques for improving WSNs network reliability can be summarized as follows:

- Link layer retransmissions.
- Increasing the one hop transmission power. This leads to longer transmission range, but very taxing on the power requirements.
- Use of ACKs and NACKs (at the link or transport levels).
- Use of multiple disjoint paths to send the same message and adding redundancy to each packet (erasure codes).

B. Wireless Sensor Networks Reliability Open Issues

As summarized in [15], wireless sensor networks data delivery reliability has room for research in the following areas:

- Design and evaluation of new mechanisms for improving reliability taking into consideration the complex behavior of the wireless channel and the interaction between the different networking stack layers.
- Ways to adaptively control the mixture of mechanisms used in the network according to the current data delivery reliability measurements and the target reliability.

- Consideration of timing aspects and the effect of reliability demands on real time requirements and on the network's ability to meet deadlines.

III. DYNAMIC BACKOFF SCHEME FOR MESSAGE DELIVERY RELIABILITY

As stated earlier, the MAC layer is responsible for per hop transmission between neighboring nodes. A function of CSMA MAC design that is implemented by the distributed coordination function (DCF) is a random back off timer that a station uses if it detects a busy medium. If the channel is in use, the station must wait a random period of time before attempting to access the medium again. This ensures that multiple stations wanting to send data don't transmit at the same time. The random delay causes stations to wait for different periods of time and prevents them from sensing the medium at exactly the same time, finding the channel idle, transmitting, and colliding with each other. The back off timer significantly reduces the number of collisions and corresponding retransmissions especially when the number of active users increases. Besides regulating access to the shared medium, the distributed coordination function (DCF) has also been used in Ad-hoc networks to achieve other goals, e.g. meeting deadlines for time-bounded applications.

Message payload	Reliability level flag	other headers
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Fig. 1. Message reliability level flag bit

We extend on this backoff mechanism to improve the message delivery reliability for certain messages. We classify messages in the network into regular messages and important messages. The message type can be determined by the MAC layer by reading a reliability flag bit embedded within the message packet header as shown in Figure 1. The message reliability flag bit will be used to set the MAC back-off timer dynamically using the equation below.

$$\text{Backoff timer} = C * \text{Random}(x) + K * R_L \quad (1)$$

In this equation, $\text{Random}(x)$ generates a random number in the range 0 to x , where x is the collision window (cw). R_L is the reliability flag of the current message (1 for regular messages, and 0 for important messages), k and C are constants. From the above formula and the reliability flag R_L value for regular messages, we conclude that they will have the longest MAC contention backoff window. Assigning values for the constant C and K will depend on

the application's requirements and the average message length.

It is important to note that the optimized values for the constants x , C and K are dependant on the average message length and they are critical to the performance of this technique. It is equally important to note that under heavily utilized or congested network, the effectiveness of this mechanism is sensitive to the MAC retry limit.

IV. PERFORMANCE EVALUATION

The effectiveness of the proposed techniques is investigated using simulation. The setting used is one source node acting as a message generator for both regular and important messages. Another node acts as destination for the messages and records the number and the latency of the messages received. We used a fixed message length (duration) of 200 units for both message types. The rate of sending important messages is fixed at one message per 3000 time units. We varied the regular messages sending rate and recorded the latency, message delivery reliability, and whether the max number of retries is reached while attempting to deliver the messages. The maximum retry limit was set to 5 for both message types, both at 10 retries, and finally 5 retries for regular messages and 10 retries for important messages. From the results in Figs. 2-7 we find that dynamic backoff improves important messages delivery probability for heavily utilized or lightly congested networks. The latency of important messages is also better than regular messages under heavy network utilization. When the network is heavily congested the different retry limits play a critical role in forcing the regular messages to be dropped from the network, thus freeing the bandwidth for the communication of important messages. Otherwise the fact that regular messages will largely outnumber important messages will give regular messages an unintended advantage as shown in Figs. 8-10.

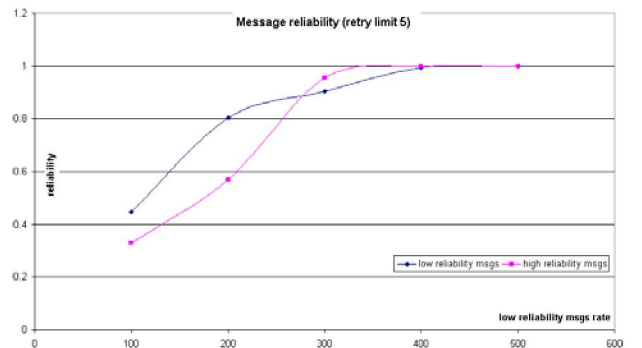


Fig. 2. Reliability vs. message rate (retry limit= 5)

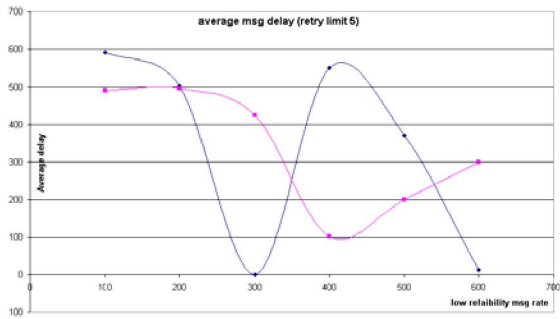


Fig. 3. Message latency vs. message rate (retry limit=5)

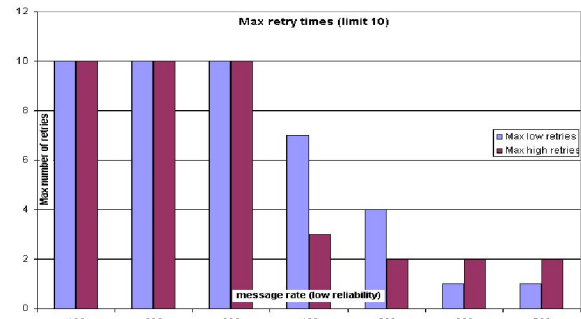


Fig. 7. Max Number of retries vs. message rate (retry limit= 10)

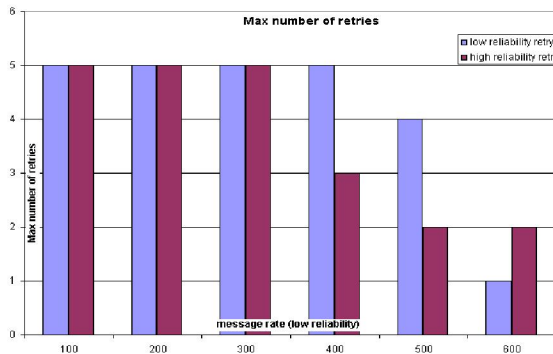


Fig. 4. Max Number of retries vs. message rate (retry limit= 5)

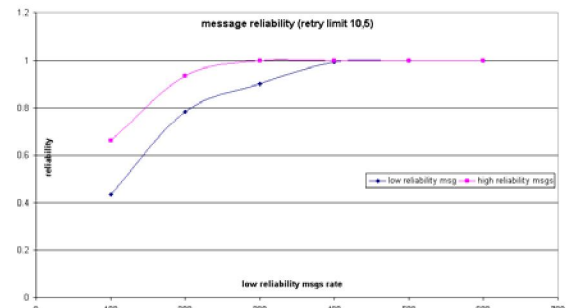


Fig. 8. Reliability vs. message rate (retry limit= 5 reg. & 10 imp.)

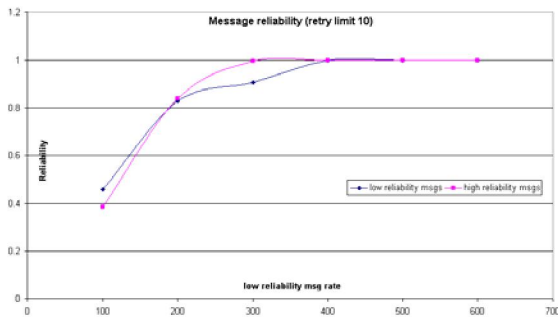


Fig. 5. Reliability vs. message rate (retry limit= 10)

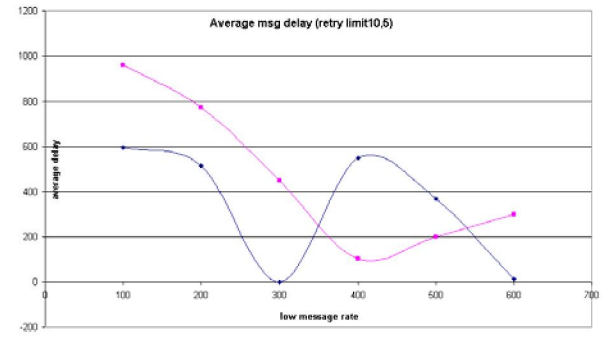


Fig. 9. Message latency vs. message rate (retry limit= 5 reg. & 10 imp.)

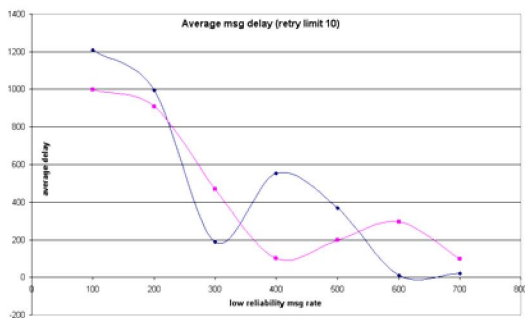


Fig. 6. Message latency vs. message rate (retry limit= 10)

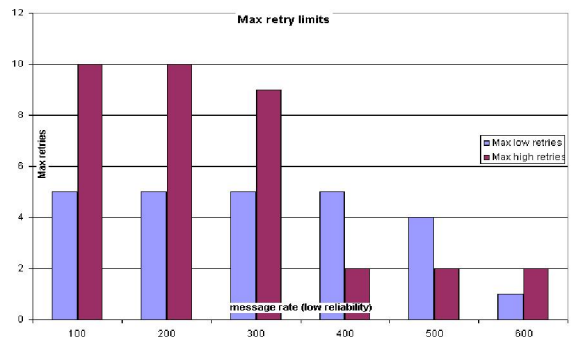


Fig. 10. Max Number of retries vs. message rate (retry limit= 5 reg. & 10 imp.)

V. CONCLUSIONS

In this paper, a dynamic backoff scheme for CSMA-type MAC layer protocols is proposed to improve message delivery reliability in wireless sensor networks. The main idea is to apply shorter random backoff times to important messages. This gives them the opportunity to test the availability of communication channel more frequently, which will enhance their chance of finding the medium idle. However, this technique might produce the opposite result by allowing the MAC layer to retry sending the important messages in a higher frequency. As a result important messages may reach their maximum retry limit, and get removed from the network. To counteract, we also propose giving the messages a maximum retry limit based on their type. In this setting, important messages will have a higher maximum retry limit. We developed a simulation program to validate our proposed dynamic backoff scheme. The messages sending rate and the maximum retransmission limit are varied. We collected data about message delivery reliability, message latency, and the number of retries used. Under heavy network utilization, our proposed dynamic backoff scheme drops normal messages leaving the network resources available to handle the delivery of important messages. It is observed that the proposed dynamic backoff scheme improves important messages delivery probability for heavily utilized or lightly congested networks.

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