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Analysis of AgRED Performance in LR-WPAN Dense Ad-Hoc Networks †

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Abstract: IEEE defines the standard 802.15.4 for Low Data Rate Wireless Personal Area Networks (LR-WPAN) to be used with Internet of Things (IoT) sensor devices. IoT devices utilizing this standard suffer from traffic congestion on a node level in dense network scenarios in real time applications. Active queue management (AQM) schemes can optimize the queues of the nodes in order to relive nodes from congestion and improve performance. This paper investigates the impact of Aggressive Random Early Detection (AgRED) AQM in dense network configuration with larger payload and higher service rate for LR-WPAN. The findings indicate better delay, throughput and packet delivery ratio when using AgRED as compared to RED.

Keywords: AgRED; RED; active queue management; LR-WPAN; WSN; IEEE 802.15.4

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1. Introduction

Monitoring and controlling several aspects of large networks has seen a breakthrough with the arrival of IoT and Wireless Sensor Networks (WSN) [1]. Sensor devices that used to utilize IEEE 802.11 (Wi-Fi) in the unlicensed spectrum suffer from congestion due to high density and larger bandwidth as specified by the standard [2]. The information that needs to be communicated commonly consist of small data that do not require high bandwidth but connectivity to the gateway and co-existence of a large number of devices that IEEE 802.11 cannot provide [3]. Therefore, IEEE defines a new standard 802.15.4 [4] to support small sensor devices that use low communication range, smaller bandwidth and low energy, but with the ability to crease much denser networks in a smaller area. 802.15.4 is the base for several other LR-WPAN [5] technologies that build on it including Zigbee, Bluetooth low energy, DASH7, ISA100.11a, 6LoPAN, and WirelessHart.

Although the problem of co-existence and appropriate bandwidth are addressed in the standard, devices used under the IEEE 802.15.4 standard are small and have limited resources, and therefore suffer from packet drops due to queue overflows. AQM techniques can be used to optimize queues of small sensors as AQM techniques are very simple to implement and do not require much in the way of computational resources. AgRED [6], based on Random Early Detection (RED) [7], provides performance improvements in severely congested networks.

The rest of this paper is organized as follows. Section 2 presents some of the work in the literature focusing on small sensor deployment. Section 3 presents the ways in which AgRED addresses the congestion in small nodes to optimize queue overflows. The results after intensive simulation and analysis are presented in Section 4, while Section 5 presents conclusions and future work.

2. Related Work

First-in-first-out (FIFO) queues implemented on devices suffer from queue overflows, which happen when arriving packets at the node mac layer are stacked waiting to be processed by the node, and no further place is available for the arriving packets. When the queue is full, all arriving packets are dropped causing packet delivery failures, connection drops and performance degradation. AQM has proven to provide better queue management as compared to FIFO queues, which optimize queues by dropping frames from the queue prematurely either from the start of the queue, back of the queue, random frames from the queue or by packet filtering. Some of the works on IoT sensor networks utilizing AQM techniques are presented in this section.

An extensive study covering several AQM techniques including proportional integral controller enhanced (PIE) [8], controlled delay (CoDel) [9], and FlowQueue-CoDel (FQ-CoDel) [10] in broadband networks and IoT is presented in [11]. The authors discuss the importance of AQM techniques in several applications, then present the test-bed with emulated bottlenecks and path conditions. The paper concludes that PIE keeps the queue small while FQ-CoDel and FQ-PIE are more suited for IoT applications. Another paper [12] proposes a deep reinforcement learning-based AQM technique with differential QoS to either improve queueing delay or throughput. The proposed scheme defines a scaling factor to achieve a trade-off between queueing delay and throughput.

3. Methodology

RED optimizes queue by maintaining an average queue length aql at all times bounded by two threshold levels min_{th} and max_{th} as shown in Figure 1. Both threshold levels are configurable parameters with max_{th} being close to the maximum queue length of the node.

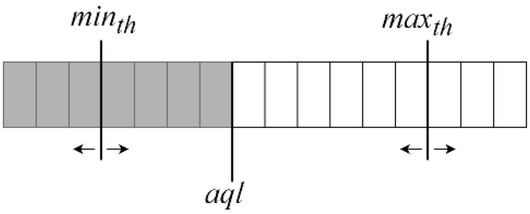


Figure 1. RED queue parameters.

RED works by randomly dropping or marking the arriving packets with a probability if the aql is between two threshold levels, while no packet dropping or marking takes place if aql is below min_{th}. Similarly, if max_{th} is defined as less than the maximum queue capacity and aql is greater than max_{th}, then all the arriving packets are dropped by the queue. Dropping enough packets will ensure that aql will stay between the two threshold levels. Parameter aql is determined by the equation below:

$$aql = \frac{q_{avg} - min_{th}}{max_{th} - min_{th}} \tag{1}$$

While the dropping probability is determined by the equation below:

$$P_d = P_{max} \times aql \tag{2}$$

where, P_{max} is also a configurable parameter with default value of 0.1, which means that each arriving packet, when aql is between min_{th} and max_{th}, will have a dropping probability of 10% of aql. RED was made to work with TCP connections so that dropped packets are retransmitted with no loss of information but it also causes the TCP sending window to shrink. Although these issues were later addressed by the research community, RED also suffers from performance drops as RED behavior still allows queue overflows [13].

AgRED modifies the linear behavior of RED such that dropping probability allows packet dropping aggressively when the aql is near min_{th}. Dropping probability of AgRED P_{AgRED} uses a sigmoid function that is most commonly used in deep learning and defined below:

$$P_{AgRED} = \frac{1}{1 + P_d} \tag{3}$$

where P_d from Equation (2) is modified to

$$P_d = \left\{ e^{-MAX(P_{AgRED})} \times \frac{e^{-q_{avg}} - e^{-min_{th}}}{e^{-max_{th}} - e^{-min_{th}}} \right\} \tag{4}$$

4. Simulation Parameters

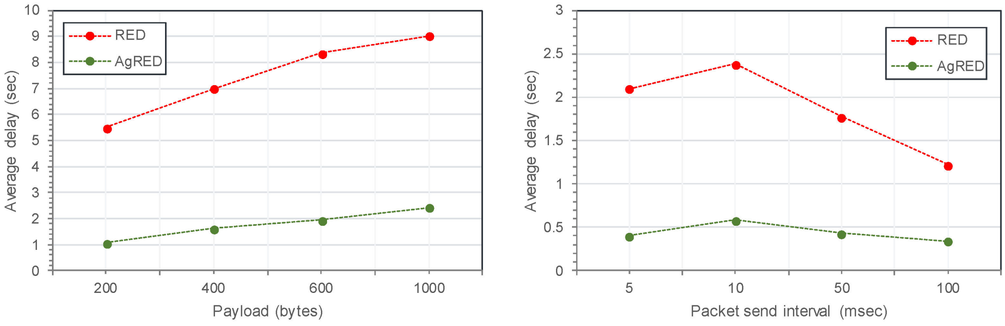
For the purpose of evaluation of AgRED performance in comparison with RED, a scenario of 500 m^2 is chosen with a dense arrangement of nodes that support IEEE 802.15.4 LR-WPAN. Simulation is run on OMNET++ simulation software with INET framework, where modifications have been carried out in RED filter module. Every simulation is repeated five times with constant seeds for random numbers generation. The routing protocol used to communicate is AODV [1], while any other routing protocol can be chosen, such as OLSR or BATMAN [14]. The nodes are following random motion using Gauss Markov mobility model from INET. The parameters that are analyzed are payload variations and send interval delay. The payload supported by IEEE 802.15.4 is 127 bytes but supports fragmentation; therefore, larger payloads can also be tested. More detailed simulation parameters are listed in Table 1.

Table 1. Simulation parameters.

Parameter	Value
MAC protocol	IEEE 802.15.4
Node data rate	250 Kbps (LR-WPAN)
Communication range	100 m (BB-WSD2C21150 sensor)
Area	500 m × 500 m
AQM techniques	RED, AgRED
Routing scheme	AODV
Payload	200, 400, 600, 1000 (bytes)
Packet send interval	5, 10, 50, 100 (ms)
Transport protocol	UDP
Node speed average	3 m/s
Queue capacity	100
Maximum probability Pmax	0.02
Minimum threshold	20 packets
Maximum threshold	100 packets

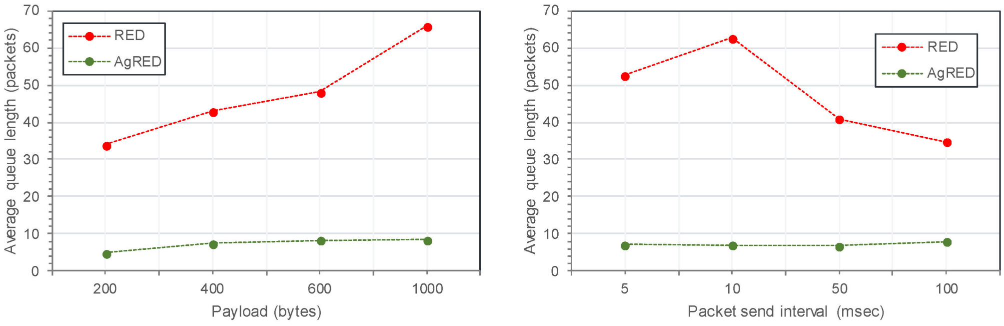
5. Results

AgRED is put against the base RED protocol for AQM for LR-WPAN in the tests. Figure 2 shows that packet delay from source to destination for AgRED is at least five times less as compared to RED regardless of the payload or packet interval. It is clear from the results that increase in payload also increases the delivery times. This is due to higher number fragmentation of packets which also increases that chance more packets are dropped randomly by the algorithm, while packet send interval relives the queue with a lesser number of packets, thereby decreasing the packet delivery times. Average queue length analysis is necessary in finding out the performance of the queue management scheme. Figure 3 shows that AgRED queue length is kept minimal, therefore allowing majority of arriving packets a place in the queue regardless of variations in both variables. With the ability to allow more packets into the queue, AgRED's ability to deliver more packets as compared to RED is shown in Figure 4. Here, the overall packet delivery reduces with increasing payload due to fragmentation; however, at the payload of 1000 bytes, the difference between AgRED and RED closes. Increase in send interval overall deliver more packets as the queue relives more often as compared to the higher frequency of packet arrival in queues. Throughput follows an inverse trend of delay as shown in Figure 5. Throughput of AgRED is twice as high as that of RED. A payload of 1000 bytes offers the lowest throughput for both RED and AgRED but still remains twice as high as RED. Packet send interval also impacts the throughput, where the lowest throughput achieved was on a 10 ms packet delay which is suspicious and further study needs to be carried out.



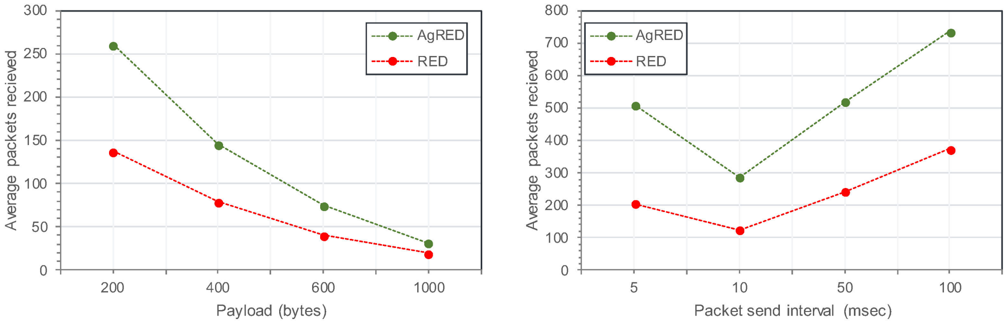
(**a**) (**b**)

Figure 2. Average delay of AgRED and RED with (**a**) payload and (**b**) packet send interval.



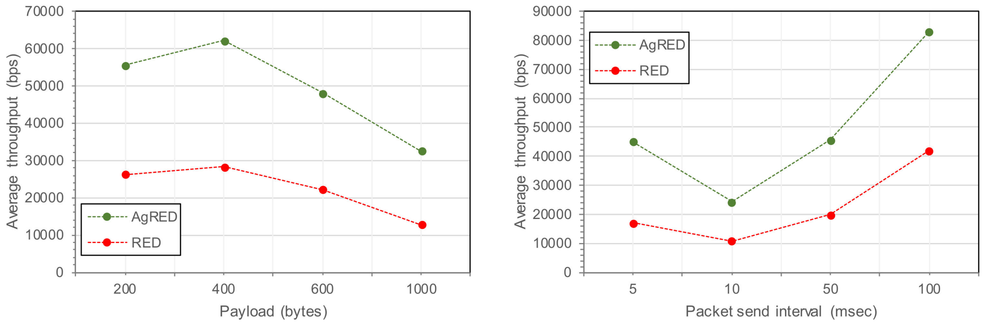
(**a**) (**b**)

Figure 3. Average queue length of AgRED and RED with (**a**) payload and (**b**) packet send interval.



(**a**) (**b**)

Figure 4. Packets received of AgRED and RED with (**a**) payload and (**b**) packet send interval.



(**a**) (**b**)

Figure 5. Throughput of AgRED and RED with (**a**) payload and (**b**) packet send interval.

6. Conclusions

Wireless sensor nodes supporting LR-WPAN standard provide better co-existence and appropriate bandwidth for communication but suffer from queue overflows in dense networks due to small queues and limited resources. AQM techniques can provide alternate dropping mechanism for fair delivery of packets. Tests were conducted on the basis of varying payload and send intervals of packets with AgRED and RED AQM techniques. AgRED in our tests performs better as compared to original RED in terms of packet delivery, throughput, delay and less queue utilization. Further improvements can be achieved by using fair queue scheduling combined with AgRED to filter larger flows in order to increase throughput and reduce resource utilization.

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