Modified Backoff Scheme for MAC Performance Enhancement in IEEE 802.15.4 Sensor Network

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Abstract: - WPAN is a low rate and low power networking technology for short range communications, and it currently uses IEEE 802.15.4 MAC and PHY layers. The technology employs special CSMA/CA to save power consumption and collision avoidance for small or portable WPAN-enabled devices. However, there are no quality of service guarantees. We propose a modified backoff scheme to reduce the collisions and enhance the throughput. Simulation results show that the proposed scheme is a good candidate for backoff scgeme in wireless sensor networks.

Keywords- wireless sensor network; 802.15.4; Backoff

1. Introduction

. IEEE 802.15.4 uses low transmission of 250kbps or less with frequency of 868MHz (BPSK/1 channel/Europe), 902~ 928MHz (BPSK /10 channels/US) 2.4GHz (OQPSK /16 channels). This is a WPAN communication technology for packet transmission at 10-50m, with low power consumption and transmitting node action. It can transmit data up to 100m. Also, the maximum size of basic data transmission packet is 128 bytes, with payload size of 104 bytes.

As for features of IEEE 802.15.4, it operates at low power, moving in tens of hops. By allocating up to 64 bits (extended address), the Node's address is makes one hybrid network of 65,000 for communication, but to minimize energy consumption, we use short addresses of 16 bits. For low-power communication, there is the method of reducing the beacon packet by 544 μs by minimizing duty-cycling. Another method would be ED(Energy Detection). There is the method of CSMA/CA is used for accessing, while the GTS (Guaranteed Time Slot) mechanism is used for QoS. Also, 802.2 LLC and SSCS(Service Specific Convergence Sublayer) used in conventional Ethernet communication were introduced for compatibility with higher layers. The purpose of this paper is to verify performance evaluation on variable Backoff method in a study on limitations of performance IEEE 802.15.4 MAC through simulation, based on which performance limitations will be studied.

This paper consists of the following. Chapter 2 describes IEEE 802.15.4 MAC functions and existing MAC methods, while Chapter 3 explains the proposed Backoff method. Chapter 4 offers simulation and performance analysis of the proposed Backoff method and existing Backoff, with conclusion in Chapter 5.

2. MAC Method in IEEE 802.15.4

2.1 IEEE 802.15.4 method

IEEE 802.15.4 describes the physical layers and MAC layers, and the protocol of higher layers requires adherence to each application environment. IEEE 802.15.4 is transmission with ⑴easy network creation in LR-WPAN, ⑵high reliability in data transmission,

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(3) low price, (4) guaranteed active and long-lasting battery time, and (5)short-distance network. Based on this, speed and node features according to frequency range and structure of used network were proposed, while GTS(Guaranteed time slot), channel access form CSMA/CA, stabilized protocol support (SSCS, LLC), ED(Energy Detection), and LQI(Link Quality indication) were standardized.

Network configuration consists of infrastructure -based star network and Ad-hoc Peer-to-Peer network. In star network, there are several devices and one central controller, which is called PAN Coordinator (PNC) in IEEE 802.15.4. This device with network operation features manages the initiation and termination points of network communication. PNC is basically the primary controller of PAN. IEEE 802.15.4 is highly sensitive to energy constraints in device for network configuration. However, PNC is often free from energy constraints. each of the nodes exists with the ability for Self-organizing and Self-healing in the network. PAN, which exists in a network configuration independent from star and peer-to-peer network, is made by selecting one identifier. PAN Identifier follows the coordinator's network policy and independent network devices having a 64bit long address or using 16bit short addresses communicate with one another.

In IEEE 802.15.4, devices exist as either RFD(Reduced Function Device) or FFD(Full Function Device). FFD is defined as bridge router role with PNC, and each node can operate as coordinator or device. Also, by collecting all load required for communication in the coordinator, there is the benefit of reducing functional element of lower device and required costs. However, such FFD and RFD operations are currently distinguished through MAC and network operation elements.

Table 1. 802.15.4 Physical Device Types

Device	
RFD	Limited to star topology
	Simple implementation(min RAM&ROM)
	Simple, leaf node (Cannot Coordinator)
	Communication only to network FFD
	Generally battered powered
FFD	Can function in any topology
	Can talk to any other device
	PAN Coordinator and Coordinator
	Can talk to any other device(FFD/RFD)
	Generally line powered
	Capable of being a coordinator

Table 1 classifies and explains FFD and RFD based on device type. FFD offers three modes of service, namely PAN coordinator, bridge router, and device for communication with RFD or another FFD. On the other hand, RFD only offers device mode and communicates only with FFD. For this reason, since RFD gets minimum resources and small memory capacity, it is suitable for light switches and manual sensors.

The slotted CSMA/CA mode is used in Beacon-enabled network in the channel access mode, and in a non-Beacon-enabled network, unslotted CSMA/CA mode is used. Also, it supports CSMA/CA mechanism and Frame Acknowledgement, and data verification through FCS (Frame Check Sequence) to support robustness. IEEE 802.15.4 supports 3 kinds of security services and uses ACL(Access Contrl List), Data Encryption, Frame Integrity to support Unsecured Mode, ACL Mode, Secured Mode.

2.2 Conventional MAC method

MAC services are largely divided into data service (MAC Data Service) and management service (MAC Management Service). The basic structure of MAC frame is the MCPS (MAC Common Part Sublayer) for communication with SSCS protocol data unit. Also, it consists of MLME for layer management and MAC database (MAC PIB) maintenance, providing MAC management service through MLME.

Fig. 1 is the CSMA/CA algorithm used in IEEE 802.15.4. Features of CSMA/CA algorithm are CCA(Clear Channel Assessment), energy saving (Battery life Extension mode), small Backoff method and BE(Backoff Exponent).

In the physical layer of CSMA/CA, CCA algorithm is used to find out if the channel is empty. This is made possible by measuring RF energy and strength of RSS signal in the antenna. RSS signal is commonly known as RSSI(Received Signal Strength Indication). If the received signal strength is under the threshold provided, the channel is defined as empty, while MAC layer becomes an empty channel for transmitting data. The super frame of nodes in PAN ID using the Beacon is classified into CAP and CFP. All frames in the CAP use slotted CSMA/CA, and if the Beacon is not used in PAN or if it is not a Beacon-enable PAN, the unslotted CSMA/CA algorithm is used. In both cases, Backoff Timer is used to run Backoff algorithm.

To control channel approach, slotted CSMA/CA maintains three counters in each station. NB shows the Backoff index to create the number of Backoff attempts during one frame transmission, and BE to create random Backoff prior to attempting transmission. CW(Contention Window) is only used in unslotted CDMA/CA, and is a counter for CCA after random Backoff period. The node's Backoff period in Slotted CSMA/CA is linked to superframe slot limits of the coordinator. That is, the number of slots is shown for possibility of channel use before starting frame transmission.

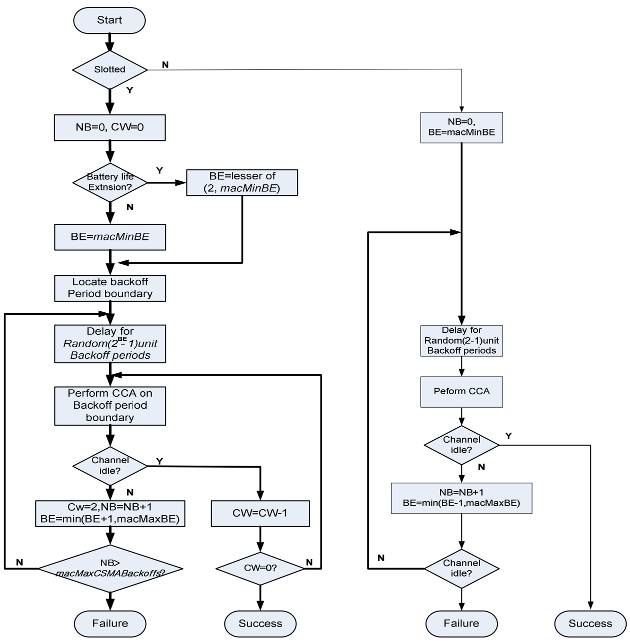

Fig 1. Slotted / unslotted CSMA/CA Process

The NB, CW and BE variable is used for CSMA-CA. The CSMA/CA in Fig. 1 is the number of time requiring Backoff while attempting current transmission. When using slotted CSMA/CA, MAC sublayer initializes NB, BE, CW values and after deciding on use of battery saving mode, the start of Backoff period is found, but unslotted CSMA/CA initializes NB, BE. NB is the number of times the CSMA-CA algorithm was required to backoff while attempting the current transmission. Then, symbols increasing as many as the random slots of Backoff period decided between 0 to $2^{BE}-1$ creates a delay, and request CCA from physical layer. If the channel is busy once out of two CW slots, the CW value is reset to 2, and after increasing NB, BE value by 1, NB value returns if it is smaller or equal to macMaxCSMA-Backoffs, or else it ends as channel approach failure. If channel is Idle for two CW slots, CW is reduced by 1 when starting frame transmission when operated with CSMA/CA, and in case of unslotted CSMA/CA, frame transmission begins right after running CCA. Energy saving mode is used for reducing Backoff delay, and maximum Backoff value is smaller in value than when energy saving mode is not used. In the slotted state, MAC sublayer first reduces CW by 1, and compares to see if it is equal to 0. If it is not 0, CSMA/CA algorithm returns to CCA. If it is 0, MAC sublayer begins frame transmission at boundary of the next Backoff time and repeats it. If channel is idle in unslotted CSMA/CA system, MAC sublayer begins transmitting frame. Backoff delay is decided as a certain value between 0 and maximum Backoff value, the lower the maximum Backoff value, the smaller the average Backoff delay, and MAC processing time is also reduced, so power consumption can be reduced.

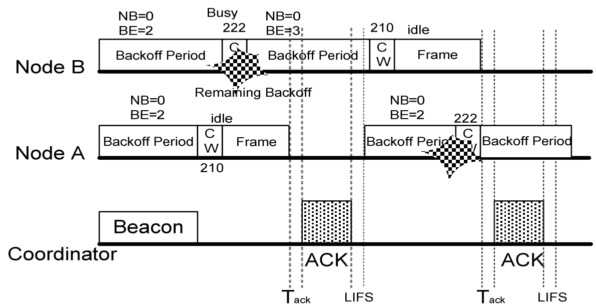

Fig 2. Data Transmission Procedure**.**

Fig. 2 illustrates the data transmission procedure for IEEE 802.15.4. The Standard, node under the supervision of a coordinator listen to the beacon issued by the coordinator. This is done by broadcasting for the current beacon interval within the beacon frame. In the active phase after the beacon, the devices can transmit data.

3. Proposed MAC Method

The proposed MAC is a method for modifying Backoff depending on conditions of general network nodes and battery saving mode. In this case, battery consumption due to node may be an issue, but from the Throughput aspect, it will bring many improvements. As shown in Fig. 3, coordinator with one PAN ID assimilates and connects with nodes desiring access to vicinity through braodcasting. First, the node adjusts to coordinator and channel choice and motive, sends acknowledgement to the coordinator, then the coordinator sends to the connected node the information based on short or expanded address created according to network policy made after the Ack data. At this time, the short address is allocated and given by the coordinator, so the coordinator can see how many devices exist in the vicinity in this process. Also in expanded address, the coordinator allocates based on calculation in 802.2. Thus, the coordinator can know the exact number of nodes through the network address connected to PNC ID.

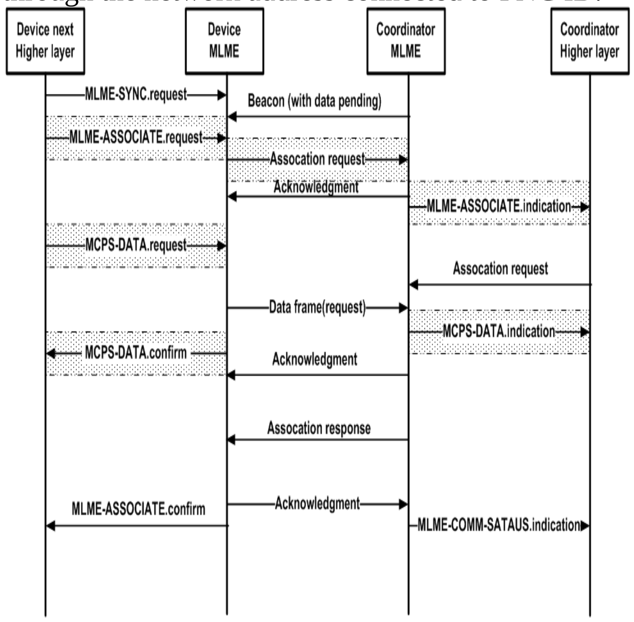

Fig 3. Association message network flow

When two nodes collide in network, delay of macAckWaitDuration and aResponceWaitTime is created. And each node must consume excess energy for extra time in Wait mode, not Sleep mode. If there are many nodes, many collisions are caused by too small a number of Backoffs in 802.15.4. To minimize collisions between nodes and solve this problem, we propose a method of modifying the number of Backoffs from 0 to 5 already in use based on nodes.

In the communication process between nodes in Fig. 3, the coordinator can find two types of parameters by detecting the number of nodes of lower devices. The coordinator can know the address value of each node based on MLME-ASSOCIATE indication/request and MCPS-DATA indication/request parameter values. Information on node address value is stored and managed in MIB neighbor table. Through this process, the coordinator can know how many nodes exist in PNC network. When broadcast is created by coordinator with one PID, each node in the broadcast range asks coordinator for association. At this time, the coordinator receiving the request for Association finds the node number in PAN Network (coordPANId). Each node runs by Backoff number set for each node through basic data on broadcasting sent by the coordinator. But if coordinator broadcasts after identifying node data, the node with PNC ID identical to that of the coordinator will renew Backoff number according to the sent Backoff value.

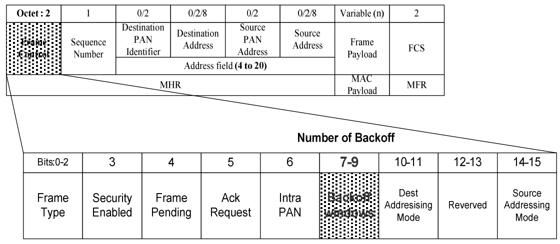

Fig 4. Frame Control Field

In the broadcasted coordinator, MHR's Frame Control has 16 bit length as shown in Fig. 4, while Reserved has 3 bit from 7 to 9 and 2 bit in 12,13. Frames 12, 13 have frame version in 802.15.4b. Therefore, it is Reserved in 802.15.4 but will be used. The algorithm value proposed in this paper uses variable Backoff Window data of 3 bit area reserved from 7 to 9. The proposed method data may be described as shown in Table 2.

Table 2. Reserved Frame Control Field

Command frame	Nodes	Backoffs	
		Nomal	ED
0x01	n<8	Backoff ≦3	Backoff ≦2
0x02	8≦n<128	Backoff ≦5	Backoff ≦3
0x03	128≦n<256	Backoff ≦8	Backoff ≦5

Table 2 and Fig. 5 are methods to reduce Backoff Delay when first node number (n) is smaller than 8 and existing Backoff BE value is set at 5, but in the proposed algorithm, BE value is proposed at 3. When BE value is 3, Backoff value of 0 to 7 is obtained in ED value 2 , so there is more collision than when BE is 5, but node is smaller than slot size and collision possibility with the same Backoff is very low. Of existing Extension mode is applied, station Backoff BE value is set at 2, so up to ED is achieved. But in the proposed algorithm, BE has a wide range from 2 to 5 depending on node status, so energy efficiency is low but collision can be minimized. The proposed method regarding Table 2 is shown in Fig. 5. Initial node status data is identified in Fig. 5, Backoff is modified based on node status, and each node's Backoff timer is the value of Backoff Period multiplied by the number of

Backoffs. Depending on use of energy saving mode later, BE value is defined in Table 2. Beacon Order value is chosen based on number of nodes and repetition, while the total number of symbols is considered.

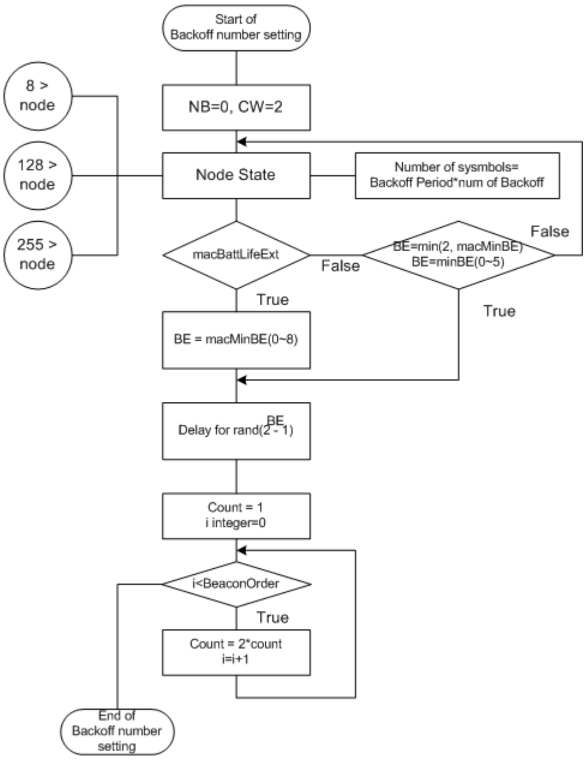

Fig 5. Proposed Backoff Method

The proposed method is not good in terms of energy consumption. But in overall operation, when considering that Wait and Resend becomes frequent due to node collisions as nodes increase, improved performance would be the result. Such change of Backoff may differ depending on throughput status when compared to existing normal cases and cases using ED [4][6].

In Broadcasting in slotted CDMA/CA, if total time is T_{all} ,

$$T_{all} = sysmbolduration \times Superframeduration \quad (1)$$

is the definition[4].

The changed count value in Table. 2 and Fig 5 is defined as Beacon's Interval, so according to Fig. 4,

$$T_{all} = T_{all} \times (count + 1) \times Status \quad (2)$$

may be the definition. Since Broadcasting occurs within a very short span of time out of overall communication time, it doesn't cause a serious problem in overall network efficiency.

4. Simulation Result

Two simulations were based on assumptions proposed in Fig. 5, Table 2. First simulation was the number of collisions in network based on nodes. Second compared network throughput aspects due to node collisions.

Table 3. Simulation Parameter

Parameter	Value
Channel Capacity	63kbps
Topology	Star
Tx Range	15 m
Beacon Order	3
Superframe Order	3
Traffic distribution	Poisson
Antenna type	OmniAntenna
Simulation time	4800 sec

Table 3 is an assumption for simluation, and as Channel Capacity value is small, the initial value of Beacon Order and Superframe Order was set at 3. In Fig. 6, Fig. 7, a comparison was done on the number of collisions in the proposed method of the Energy Detection status and in normal status. Overall, with more nodes, collision in the network increased in astronomical numbers. Fig. 6 compares collisions in the existing and proposed Backoff Schemes. It is the collision graph when BE is 2. The proposed model showed about 30% improvement in Energy Detection(ED) over the existing model. It shows that more collisions occur in ED than in normal mode, and that Proposed Scheme has less node collision than Traditional Scheme. Collisions suddenly and drastically increased from 200 network nodes, with partial reduction in proposed performance efficiency.

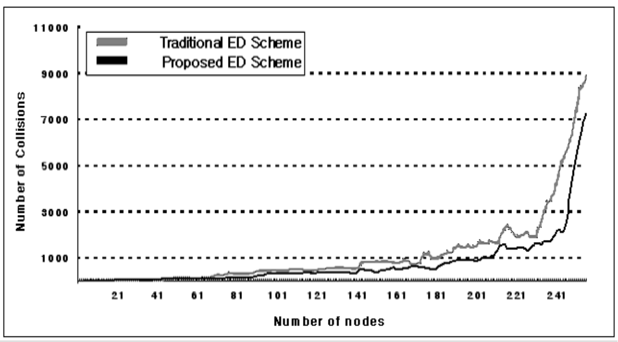

Fig 6. Number of collisions in Energy Detection

Fig. 7 shows the increase of collision in normal mode. When the method in Table 2 is applied, performance is similar or lower than when nodes are less. But increasing nodes show better results, and more collisions occur when nodes number 128 or more. But as nodes rise over 230, the result was of course better than existing, but was less than 128-230 as shown in Proposed Scheme.

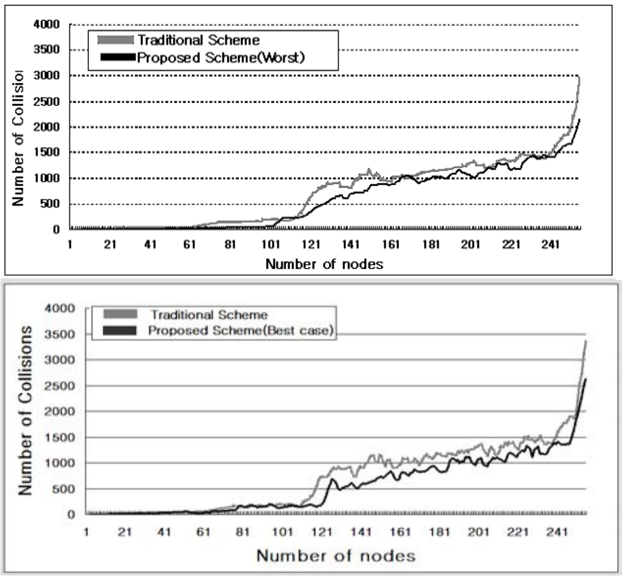

Fig 7. Number of collisions in normal mode

Fig. 8 shows the problem of more collisions than existing, when node is small. And in terms of performance, as broadcasting is periodically done, delay is caused by less nodes, resulting in a drop in Throughput performance. In the proposed paper, there is an issue of periodic broadcasts for controlling Backoff network. But from the network's perspective, broadcast is to be done within a very short time (3.82ms~10ms), and broadcast after communication between node and coordinator is also very short, so it doesn't have a big impact in the network situation.

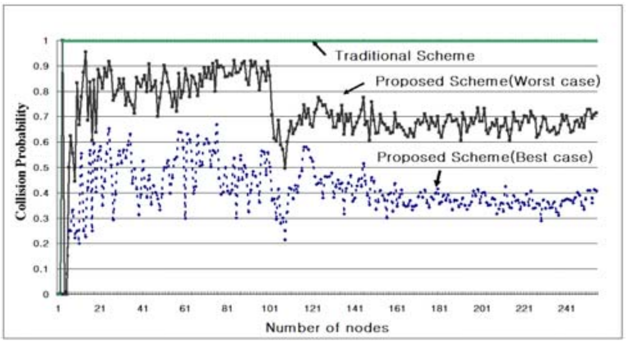

Fig 8. Relative number of collisions in normal mode

Fig. 8 is a graph relatively comparing the proposed result with existing result as 1 to show how much improvement is made. As mentioned before, when nodes are small, the proposed algorithm's collision shows smaller increases when nodes increase compared to existing status.

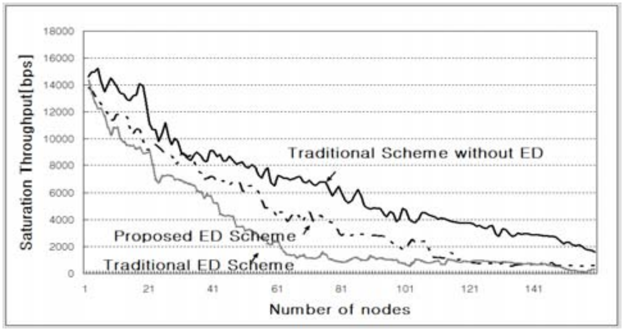

Fig. 9 Saturation Throughput at ED

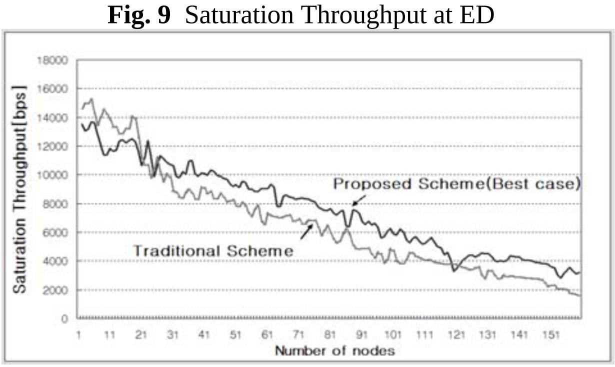

Fig. 10 Backoff and Throughput based on node

Fig. 9 and Fig. 10 compares overall performance following collision. Simulation was based on the same assumption as node's collision graph. Energy loss from each transmission quantity brings the same result as energy consumption from load of packet size following each node. Fig. 9 and Fig. 10 shows the result of Saturation Throughput regarding Data rate of Infrastructure Network. The Traditional Scheme without ED in Fig. 9 is the data transmission quantity when existing Backoff algorithm is applied in normal status, and the Proposed ED Scheme is the result of applying the proposed Backoff algorithm. As for Traditional Scheme, it is the normal status Throughput performance. Nodes started at 3, and comparison was made based on 160 nodes. When compared with lower times, the overall throughput performance dropped when using ED mode than in normal conditions, and such conditions differed greatly as nodes increased. Also, Fig. 9 shows that if ED is applied, the same throughput of general traditional method id not obtained through the proposed Backoff algorithm, but performance is better than with ED. Of course, in this case, the result is less efficiency in energy consumption, but its better for Throughput. When compared to traditional, the result shows decrease in throughput between 3 nodes to 15 nodes. Although nodes differ depending on the number of simulations, better throughput was obtained than with traditional method generally when network is made with 8 to 16 nodes. When seeing the two graphs, network throughput improvement is increased with the increase in nodes in terms of better Backoff performance in the network.

5. Conclusion

Traditional Backoff method and active Backoff method based on node status will show increase in symbols due to increase in Backoff from traditional. And these Backoff symbols will cause increase in total time. Also, efficiency will clearly drop from the energy perspective. But in a network with many nodes, the impact of Backoff symbols was found to be very small. In fact, simulation results show that decrease in node collision leads to throughput increase in terms of network performance. However, when nodes are few, the broadcasting time and Backoff variability dropped in terms of performance. An algorithm with a more active Backoff method is suggested from future studies.

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