Multi-channel MAC Protocol for Real-time Monitoring of Weapon Flight test in Wireless Sensor Networks

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Abstract— **In this paper, we propose the priority based multi-channel MAC protocol with single radio interface for the real time monitoring of the flight test of weapon systems. Concurrent transmissions with multi-channel of sensor nodes can improve the network throughput compared with single-channel transmission in wireless sensor networks. Our proposed MAC protocol has two operation modes. First is 'Normal' mode and second is 'Priority' mode. In normal mode, nodes are operated on normal CSMA/CA. And nodes have different priority depending on a sensed signal level in priority mode. High priority nodes can use more transmission channel for data send than low priority nodes. This method can guarantee successful transmission of important data generated by high priority nodes. The Class of a node is determined by own sensed data, in 'Priority' mode; nodes have three degrees – Class A, Class B, and Class C. When a sensed data of each node exceeds specific threshold value, each node has specific class respectively. High class node has low backoff exponents and can use more transmission channel. This mechanism allows that high class node has more transmission opportunity. It guarantees transmission of important data generated by high class nodes.**

Keywords- Multi-Channel; Wireless Sensor Network; MAC Protocol; Weapon Flight Test; Test Command and Control.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) [1-3] are used over a wide range such as military application, environmental monitoring, medical care, smart buildings and other industries. Energy efficiency is a main objective in most of the Medium Access Control (MAC) protocols for WSNs [4–7]. Other parameters such as bandwidth utilization, low-latency, and scalability are mostly ignored or dealt with as secondary objectives. However, bandwidth and low-latency are as important as saving energy in some applications such as military, surveillance, fire, and intrusion detection which are required a real time monitoring.

Real-time monitoring is one of the prime necessities of a flight test of weapon systems for the test command and control and the safety of person and property. A flight test of weapon systems are very dangerous and occur within short spans of time. Besides, the test is performed in a wide area and has a difficulty in a wired connection for a transmission of sensed data.

The flight test is an event-triggered application [8] in which sensor nodes do not transmit any data unless a relevant actual event (i.e. a explosion and a crash) occurs. When sensor nodes detect event, they send a sensed data to the sink at the same time. It can generate a traffic burst in the network. Because an event typically triggers many sensor nodes concurrently, the occurrence of traffic bursts produced by different nodes is highly correlated in time. Bursty or heavy wireless communication in one location (or node) may lead to contention for channel access by the nearby sensor nodes. WSNs for the flight test are required efficient and timely collection of large amounts data with high resolution. However with a single channel, WSNs cannot provide these requirements because of radio collisions and limited bandwidth.

Existing MAC protocols are not well-suited for real time monitoring of such event triggered applications with large amount of data. Characteristics of the event in a flight test of weapon systems are different from ordinary environment. We may not know exactly the event area in a wide test zone and the event occurrence time is very short. Therefore, schedule based multi-channel protocols is not appropriated to a real-time monitoring of a flight test of weapon systems. A scheduled multi-channel scheme is needed to negotiate time and procedure before data packet transmission between the sender and receiver node. A data of a event area is the interest information which is more quickly transmitted to sink than other area.

So we design the multi-channel communication protocol based on the modified Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) over a single radio for WSNs in order to improve network throughput and provide reliable and timely communication services for real time monitoring of the flight test.

Proposed MAC protocol adds a specialized priority factor under the weapon flight test environment at normal slotted CSMA/CA mechanism. This MAC protocol gives high transmission priority to the inner nodes of event area than the outer nodes. Furthermore, this MAC protocol can get not only collision reduction effect between nodes in whole sensing area but also guarantee transmission of priority nodes.

Our proposed MAC protocol has two operation modes. First is 'Normal' mode and second is 'Priority' mode. In

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normal mode, nodes are operated on normal CSMA/CA. Also nodes have different priority depending on a sensed signal level in priority mode. High priority nodes can use more transmission channel for data send than low priority nodes. This method can guarantee successful transmission of important data generated by high priority nodes. Class of a node determined by own sensed data, in 'Priority' mode and class of nodes have 3 degree – Class A, B and C. When sensed data at each node exceed specific threshold value, each node has specific class. High class node has low backoff exponents and can use more transmission channel. This mechanism allows that high class node has more transmission opportunity. It guarantees transmission of important data generated by high class nodes.

The rest of this paper is organized as follows. Section 2 reviews the related works. Section 3 presents the proposed scheme based priority in details. Section 4 presents performance evaluation through simulations. Finally, Section 5 concludes this paper with summary and directions for future work.

II. RELATED WORKS

Researchers have proposed multi-channel MAC protocols [10-15] that exploit multiple channels to increase the network throughput by eliminating the contention and interference on a single-channel in WSNs. WSNs have some limitation such as limited computation, low bandwidth, small MAC layer packet size, battery-operated power, and so on. Therefore, multi-channel MAC protocol for WSNs should consider the minimum control overhead possible in channel negotiation. Channel negotiation packets cannot be ignored as small overhead.

Multi-channel MAC protocols can be classified into three categories [9]: scheduled protocols [10-12], contention protocols [13, 14], and hybrid protocols [15].

A. Scheduled multi-channel protocols.

In this scheme, a time slot in TDMA frame for data transmission is allotted to every node which is unique in its 2-hop neighborhood. This guarantees collision-free medium access, and protocol does not waist energy and bandwidth on competition and collisions.

MC-LMAC [10] proposed a multi-channel scheme based on LMAC which allows the node to utilize new frequency channels on-demand, if the network reaches a density limit. This method is composed of two phases, one where the nodes try to select timeslots according to the single channel in LMAC rule and the second involves nodes which are unable to grab a timeslot in the first phase invite the neighbor nodes which are free to listen to them on an agreed channel or time slot.

TMCP [11] is a tree-based multi-channel protocol for data collection applications. The goal is to partition the network into multiple subtrees with minimizing the intra-tree interference. The protocol partitions the network into subtrees and assigns different channels to the nodes residing on different trees. TMCP is designed to support convergecast traffic and it is difficult to have successful broadcasts due to the partitions. Contention inside the branches is not resolved since the nodes communicate on the same channel.

In TFMAC [12], a channel scheduling mechanism is used to manage and decide when a node should switch channel to support the current communication requirements. TFMAC requires Time Synchronization and it uses single half duplex transceiver. This protocol divides each channel into time slots and the slot scheduling has been done for the medium access. The frame has been divided into contention access period where the slot scheduling and channel allocation has been done and contention free period where the data transfer has been done.

B. Contention-based multi-channel MAC protocols

Contention-based multi-channel MAC protocols use neither a predetermined transmission schedule nor the frame is divided into time slots. Instead, contention procedure is conducted at the beginning of each frame, beforehand every transmission, in order to avoid collisions. Contention-based MAC protocols allow small delay and high throughput in cases of low traffic.

MMSN [13] and TMMAC [14] have attempted to make use of multiple channels by assigning different channels to different nodes in a two-hop neighborhood to avoid potential interference. They use a different channel from its downstream and upstream nodes. Time slots are used to coordinate transmissions in these protocols. They also require precise time synchronization at nodes with frequent channel switching delays and scheduling overheads especially for high data traffic. In the multi-hop flow, nodes have to switch channels in order to receive and forward packets. This causes frequent channel switching and potential packet losses. In order to prevent packet loss these protocols use some negotiation or scheduling schemes to coordinate channel switching and transmission among nodes with different channels. They need many orthogonal channels for channel assignment in dense networks.

C. Hybrid protocols

These protocols combine principles from previous two methods. The frame is divided into time slots, but slots are assigned to receivers instead of transmitters. In the absence of traffic, hybrid protocols are more energy efficient then scheduled protocols, since each node need to be awaken to receive data only once per frame. Although hybrid protocols require contention of the potential transmitters at the beginning of each slot, contention mechanism is simpler and wastes less energy than with contention-based protocols since there is always only one receiver.

Y-MAC [15] is a hybrid multi-channel MAC protocol. to TDMA, Y-MAC divides time into frames and slots, where each frame contains a broadcast period and a unicast period. Every node must wake up at the beginning of a broadcast period and nodes contend to access the medium during this period. If there are no incoming broadcast messages, each node turns off its radio awaiting its first assigned slot in the

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unicast period. Each slot in the unicast period is assigned to only one node for receiving data. This receiver-driven model can be more energy-efficient under light traffic conditions, because each node samples the medium only in its own receive time slots.

III. Protocol Description

Our proposed MAC protocol is based on the Multi-Channel mechanism. Our proposed MAC protocol distributes the nodes in a network to multiple channels, so this method can reduce collisions between nodes in a network and improve network transmission efficiency [16, 17]. Our MAC protocol has two operation modes. First is ‘Normal’ mode and second is ‘Priority’ mode. Change of this operation mode is controlled by outside signal. In ‘Normal’ mode, nodes in a network operate on normal CSMA/CA what use Multi-channel manner. And, in ‘Priority’ mode, nodes in a network have priority for data transmission. High priority nodes can use more transmission channel for data send than low priority nodes. This method can guarantee successful transmission of important data generated by high priority nodes.

The Class of a node is determined by own sensed data, in ‘Priority’ mode; nodes have three degrees – Class A, Class B, and Class C. When sensed data at each node exceed specific threshold value, each node has specific class. High class node has low Backoff Exponents (BE) and can use more transmission channel. This mechanism allows that high class node has more transmission opportunity. It guarantees transmission of important data generated by high class nodes.

A. *Normal operation state*

In a general situation, proposed MAC protocol operates normal CSMA/CA. But, nodes in a network can use multiple channels, and perform not only time backoff but also channel backoff [18]. This twin backoff mechanism is more efficient to avoid collisions between nodes in a network. All nodes have same CW (Contention Window) and BE and can use three channels.

When there is a need to transmit sensed data, they first generate backoff value and select transmit channel randomly. And perform CCA (Channel Clearance Assessment) at on time and selected channel. If selected channel is idle, perform data transmit. Nor perform new time and channel backoff using new CW and increased BE value. Detail description about this procedure represented in Fig. 1.

B. *Priority State*

In Priority state, each node verifies own sensed value. If this value exceed specific threshold, that node has transmission priority. Nodes what get high priority, has more accessible data channel and low BE value. So, these high priority nodes can access media more easily than low priority nodes. Each node in a network can get one of 3 classes- Class A, B and C.

Class A node can access all channel and has minimum max BE value. These nodes can access media easily than other class nodes. Class B node can use 2 of 3 channel and Class B node only use one data channel and has maximum max BE value. Fig. 2 represents procedure of priority state. Each node decides own transmission priority when sending data generated by pre-determined threshold value. Follow own transmission priority, each node select BE and TX channel. After select BE and TX value, each node perform CCA on backoff period boundary. If channel is clear, nodes perform data sending sequence. But, if channel is buys nodes perform backoff sequence. In backoff sequence, a node only re-select TX channel.

Class A node can access not only own channel but also channel of class B and C. And, class B node use own channel and class C’s channel. All node in a network can access class C’s channel. So, in the class C’s channel occur many collision between all nodes in a network. We also propose channel selection weight factor for reduce this collision at common channel. Each node has weight factor for select own channel. Nodes in a network select own channel more frequently by effect of this weight factor.

IV. Simulation Results

In this paper, we evaluate our proposed MAC protocol via simulation. We compare average media access delay and total number of successful media access. First, we compare all node in a network can access all channels with our proposed MAC protocol.

Fig. 3 shows average media access delay and total number of successful media access by channel allocation method. Uniform allocation method means all nodes in a network can access same multiple channels and classified allocation method mean some node has higher media access priority than other nodes. Like table 1, Class A node can access all data channel but class B node can access 2 of 3 data channel and class C node can access only 1 channel.

TABLE I. Number of Allocated Channel

	Number of allocated channel	
	Uniform allocation	***Priority based allocation***
Class A	3	3
Class B	3	2
Class C	3	1

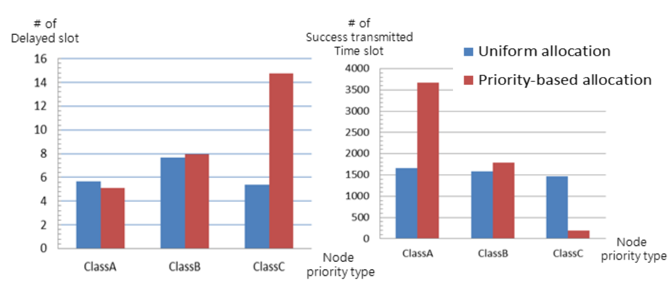

Figure 1. Average Delay and Number of Tx Success.

In case of uniform channel allocation method, average channel access delay and total number of successful media access of each node in a network is very similar. But, in priority based allocation mechanism, number of successful media access of class A nodes what can use more channel than other low priority nodes is larger than other class nodes.

Next simulation result compare uniform channel allocation ratio with priority based channel allocation ratio. Allocation ratio represented in table 2.

TABLE II. CHANNEL ALLOCATION RATIO

	Uniform channel allocation ratio	**Priority-based channel allocation ratio**
Class A	1:1:1	1:1:3
Class B		1:2
Class C		1

Fig. 4 shows number of unused channel at each channel. In case of don't use weight factor for channel allocation, almost slot in #1 channel has been used but a lot of slot in #3 channel – only for class A nodes, don't used. But in case of we use weight factor for channel allocation, the number of unused slot in #3 channel is lower than don't use weight factor.

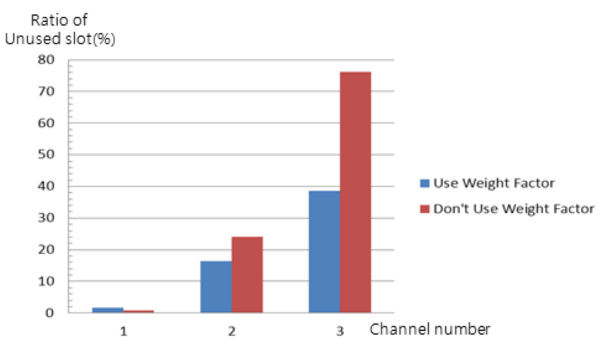

Figure 1. Ratio of Unused Slot at Each Channel.

Next Fig. 5 shows simulation result when each class has different maximum BE and minimum BE value. Table 3 shows this BE value.

TABLE III. MAXIMUM AND MINIMUN BE VALUE

	Same BE		**Different BE**	
	minBE	***maxBE***	***minBE***	***maxBE***
Class A	0	3	0	3
Class B	0	3	1	4
Class C	0	3	2	5

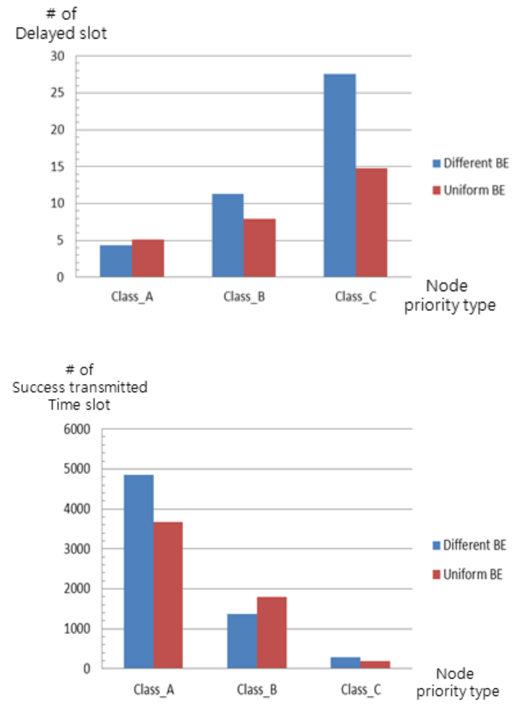

Figure 2. Average Delay and Number of Tx Success.

V. CONCLUSION

Real-time monitoring is one of the prime necessities of a flight test for the test and evaluation (T&E) of weapon systems. Data of a event area is the interested information which is reliable and quickly transmitted to sink than other area.

Existing MAC protocols in WSNs are not well-suited for real time monitoring of the flight test with large amount of data. Therefore we proposed the new multi-channel MAC protocol based on the modified CSMA/CA, which has two operation modes. In normal mode, nodes are operated on normal CSMA/CA. And nodes have different priority depending on a sensed signal level in priority mode. High priority nodes can use more transmission channel for data send and has lower backoff exponents than low priority nodes. It guarantees transmission of important data generated by high class nodes.

In the future, we plan to setup testbed sensor network system and evaluate the performance of the proposed MAC.

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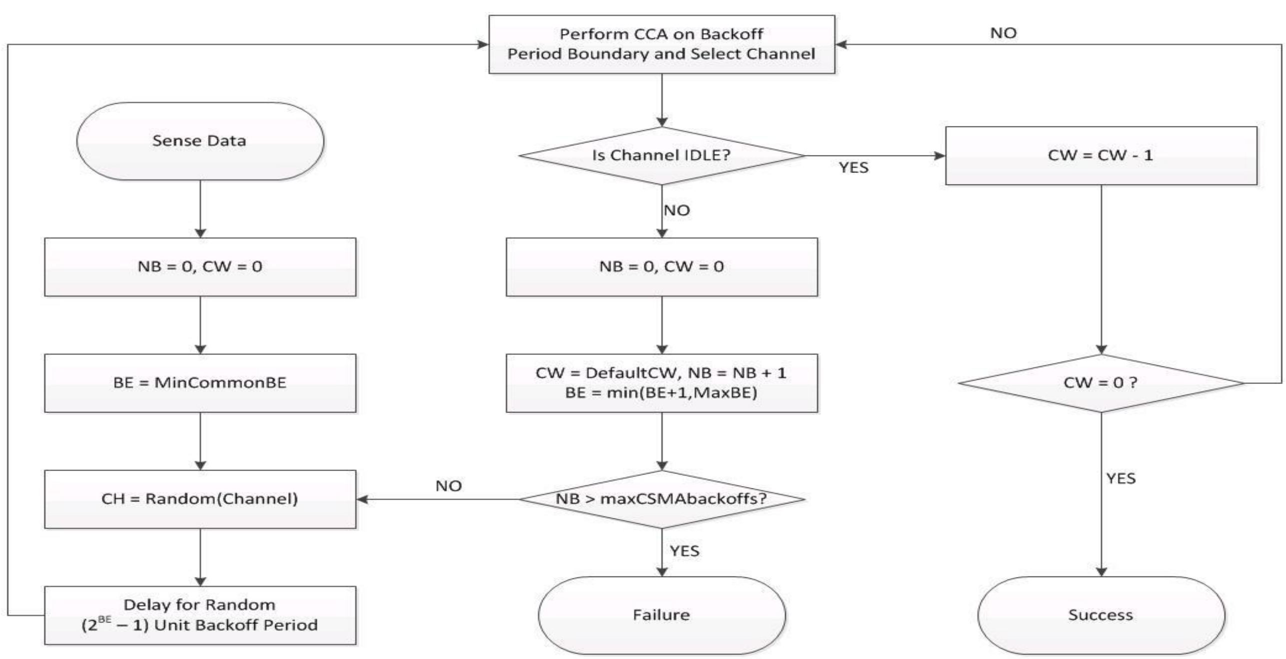

Figure 3. Normal State Procedure Flow Chart.

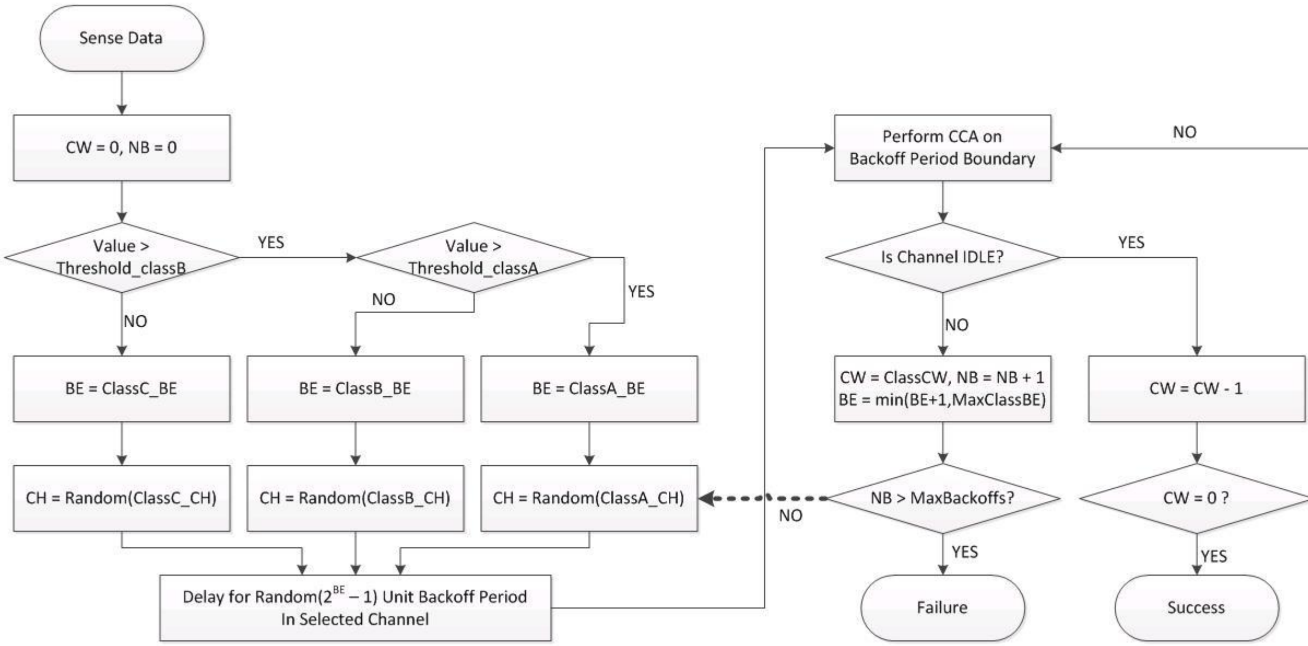

Figure 4. Priority State Procedure Flow Chart.