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Proposed Hybrid MAC Layer Design for Priority Application Usage in Wireless Sensor Network (WSN)

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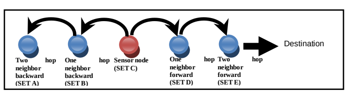
Graphical abstract



Abstract

The design of Medium Access Control (MAC) layer in Wireless Sensor Network (WSN) is very important because it gives significant impact in network performance especially in term of energy consuming. Contention Access method which is Carrier Sense Multiple Access (CSMA) will encounter collision problem when more than one node want to access the network simultaneously. Meanwhile, the issue in slotted access which is Time Division Multiple Access (TDMA) is channel utilization when the usage of the slot is neglected and wasted in transmission network. In this paper, we propose a hybrid MAC that combines both strengths of CSMA and TDMA in one protocol while avoiding their weaknesses to improve the network performance. The simple and efficient transmission in CSMA method will be used in neighbor discovery (ND) and slot allocation (SA) process. For data transmission, non collision transmission method which is TDMA will be used and it will be changed to CSMA depending on the contention level of the channel. This proposed protocol is suitable for priority application usage where the important information will arrived at the destination in acceptable delay time.

Keywords: TDMA protocol, network model, hybrid MAC, slot allocation

1.0 INTRODUCTION

The trade-off of energy usage with high throughput in WSN environment becomes a challenging task in the WSN protocol design. In WSN, the protocol design must provide less energy consumption while maintaining the throughput of the network. Each layer in WSN model plays a significant role in the network. One of them is MAC layer, which is responsible to control the communication directly between each node in the network. The performance of MAC layer gives a big effect on nodes' energy consumption due to its ability to control the physical radio directly [1].

MAC layer has the responsibility to choose which nodes in the network that is allowed to access the medium, when and how long the selected node is going to access the network and lastly, how the node accesses the network. If there is no MAC layer, multiple nodes might try to access the medium simultaneously and lead to collision. When collision occurs, energy consumption will increase due to retransmission of data and hence will decrease the throughput of the network. For priority application usage, this problem must be tackled to make sure the urgent data is not loss or collide in the transmission. Reliability issue is also important for priority application usage. However, this issue is always considered at the transport layer [2].

Energy efficiency is an important requirement in designing MAC Layer in WSN. Besides that, the design must include fairness, low latency and scalability due to the dynamic topology changes in WSN environment. There is a lot more issues that must be considered when designing MAC layer such as signal loss in wireless channel, collision at the receiver's end, resource constrain (energy, bandwidth, network topology), hidden node and exposed terminal problem.

The existing technique in MAC layer are contention based and schedule based. Both techniques have strength and weakness when applied in WSN environment. The first technique is contention based (CSMA) which means if the node wants to access the medium or send the data; it should compete with other node to get the channel [1]. Even though CSMA technique is scalable and simple, it is faced collision issue due to hidden terminal problem. Hidden terminal problem occur when two nodes that is out of range with each other intended to transmit their data to the same node in the network. Both nodes did not hear each other's signaling and assumed that the channel is idle. Then, both nodes transmit the data and cause the collision at the destination. For priority application usage, this technique is not suitable to be used to transmit the data.

The collision problem in CSMA technique is encountered in schedule access (TDMA) technique. In TDMA technique, time is divided into a number of timeslots and each node in the network can access the channel in its own timeslot [3]. This technique will naturally avoid collision problem but it needs precise time synchronization and has high complexity in the scheduling process. This technique is suitable to be used for data transmission but not for exchange signaling between neighbor nodes.

In this paper, we proposed a hybrid MAC layer protocol design that combines the strength of both aforementioned techniques. CSMA technique will be used for exchanging of signaling (control message) at the setup phase. For transmission of data, TDMA will be used and it can be changed to CSMA depends on contention level of the channel. These protocols are design for priority application usage that needs the data to arrive in the real time such as video application, medical information and emergency application.

This paper is organized as follows. This section gives an introduction about MAC layer. Section 2 briefly explains the related works on TDMA protocol, existing hybrid MAC layer and slot allocation. In the section 3, the proposed Hybrid MAC protocol design will be described thoroughly. In the same section, the random phase, the proposed slot allocation and transmission data phase are explained in detail. Section 4 describes the system model description that is going to be used in this project. Section 5 shows the preliminary result for neighbor discovery. Finally, Section 6 concludes this paper and gives some insights of the future works.

2.0 RELATED WORKS

The early work in TDMA protocol used centralized approach to assign the timeslot for each node in the network. Then, the distributed approach was introduced to improve the network performance by removing dependency on the central manager [4], [5], [6], [7]. In distributed TDMA approach, each sensor node is allowed to assign itself a timeslot by collecting its neighborhood information [8].

Lightweight Medium Access Control (LMAC) [4] conserve energy by switches its transceiver to standby state when the node is not needed for transmission. In Eyes Medium Access Control (EMACs) [5] protocol, different modes of node are proposed to reduce energy consumption in the network. LMAC improve EMACs protocol by eliminating one session in timeslot frame. There are only two session in LMAC timeslot frame which is control message (CM) and data message (DM). In LMAC protocol, when a node has data to be transmitted, it waits until its timeslot comes up and transmits the packet without collision or interference to other transmission [9]. To assign timeslot in LMAC protocol, there are four operation stages, namely initialization stage, wait stage, discovers stage and active stage. The limitation of this protocol is LMAC only permit node to own a single timeslot per frame.

Enhance Lightweight Medium Access Control (eL-MAC) [6] introduced Active/Sleep Mechanism for efficient energy usage with predefined duty cycle and leveled Timeslot Synchronization for synchronization process. In eL-MAC there are only three operation stages to obtain timeslot compared to LMAC that have four stages. eL-MAC protocol increased energy efficiency by combining waiting stage and discovery stage to decrease the time for node to turn into active state. However, in eL-MAC protocol, channel is not fully utilized because once a node gets its timeslot, it is not released to other node and the implementation of eL-MAC is only limited to 9 nodes. eL-MAC protocol solve this problem by introducing Adaptive Multi-Timeslot Allocation (ATMA) mechanism that allows the node to control more than one timeslot same as approach that is used in Adaptive, Information Centric and Lightweight MAC (AI-MAC) protocol. But AI-MAC used different mechanism to assign multiple timeslots to certain node and vary the number of slots depending on the amount of data [7]. The distributed approach used in TDMA technique makes the network more scalable when the topology changes in the WSN environment.

Nowadays, many researchers are looking forward to design hybrid MAC layer that combine CSMA and TDMA in one protocol design in wireless network [10][11][12][13].The advantage of the hybrid MAC is its easy and rapid adaptability to traffic condition which can save a large amount of energy [13].

Zebra MAC (ZMAC) [10] used Distributed Randomized Timeslot Assignment Algorithm (DRAND) [14] approach in assigning timeslot. For transmission data, a node can be in one of two modes: low contention level (LCL) which is the node in CSMA mode and high contention level (HCL) which is the node in TDMA mode. Node will be in HCL when it receives explicit contention notification (ECN) message. Otherwise, node will be in LCL mode. In HCL mode, owner of the slot have high priority compared to non owner, but if the owner does not have data to send, non owner can use the slot. This feature achieves high channel utilization but there is possibility collision happen with owner of the slot if the transmission that starts in the previous slot across over an HCL slot.

In [11], the paper introduces Mobility Aware and Energy Efficient MAC (MEMAC) protocol which is an improved version of Scalable and Energy Efficient Hybrid-Based MAC (SEHM) protocol [13] in term of network mobility. The frame transmissions of the MEMAC protocol are divided into two as shown in Figure 1 which is mini slot and a normal slot. In mini slot frame, contention access is used for transmitting and receiving short control message. Meanwhile, in normal slot, schedule access is used for transmitting data message. The frame for normal slot can be dynamically adjusts depending on the mobility and traffic condition (i.e. the number of time slot is increase and decrease according to the number of nodes that have data to be sent). This protocol can achieve a significant amount of energy saving by avoiding slot wastage because the slot will only be given to the node that has data to send. But this protocol is depending on the cluster head (CH) to assign the timeslot.

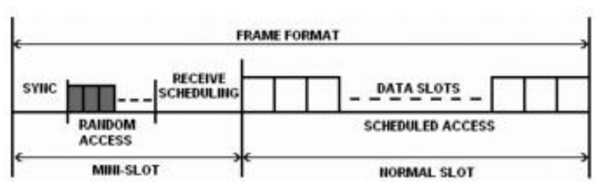


Figure 1 MEMAC frame format structure

Mobility Adaptive Real-Time TDMA MAC (DynaMAC) [12] is one of the Hybrid MAC that is designed for real-time traffic application like voice streaming. This protocol introduces a novel segmentation concept that allows the higher layer to balance the end-to-end delay with different length. With DynaMAC, packets on routes with multiple hops can be transmitted faster. Random phase in this protocol is accessed using CSMA without exponential backoff and used to exchange control data. While schedule phase is accessed using TDMA and accommodate the real-time traffic. There is buffer slot (l_{buf}) at the end of each segment in schedule phase that is used for collision resolution as describe further in [12]. Figure 2 show the frame format for DynaMAC which is different from ZMAC and MEMAC.

Each Hybrid MAC design used different method to assign timeslot for each node in the network. In multihop WSN scenario, reused timeslot is a challenging issue as to make sure that two nodes within two-hops are not assigned to the same slot. For example ZMAC used other protocol which is DRAND to assign timeslot. DRAND protocol ensures that when a node decides its timeslot, it always select the minimum timeslot that is not taken by its two hop neighbor. This protocol will ensure there is no overlapping with nodes within two-hop neighbors that choose the same slot. There are four stages in DRAND which is idle, request, grant and release. Each node in the network should go through these four stages before obtaining timeslot, and this protocol increases delay for slot allocation.

SEHM [13] protocol used centralized approach in slot allocation where the sensor network will be divide into cluster. Each of nodes in the network is allow to content to be a cluster head. There is two TDMA slotting in SEHM protocol which is between nodes and cluster head and cluster head with base station. This protocol lack of scalability because only cluster head can talk with base station.

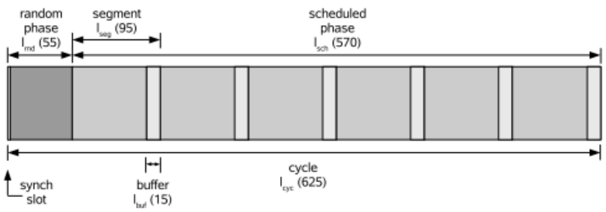


Figure 2 DynaMAC frame format structure

3.0 PROPOSED HYBRID MAC DESIGN

This section explains the proposed Hybrid MAC protocol design. We combine CSMA and TDMA in one frame structure. We also implement some of the advantages from ZMAC protocol and eL-MAC protocol. There are two phases in the frame structure of proposed protocol design as shown in Figure 3. The length for first phase which is random phase is small compared to second phase which is data transmission phase. In first phase, there is two tasks to be done; 1) neighbor discovery to collect all the information about one and two hops neighbor and 2) slot allocation mechanism to give timeslot to all the sensor nodes in the network. The detail information of slot allocation will be explained in section 3.2.

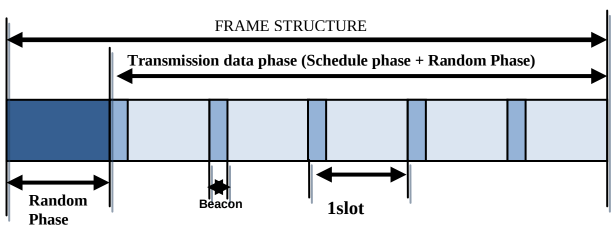


Figure 3 Propose frame structure

For data transmission phase, beacon will be transmitted at the beginning of each timeslot by the owner of the slot. Beacon is used to transmit information about synchronization message and to indicate the status of the owner of the slot whether it has data to send or not. After that, the slot will be set in TDMA mode before switched to CSMA mode depending on the contention level in the network. The detail of the process in second phase will be explained in section 3.3.

3.1 Random Phase

Our proposed protocol starts with random phase process which implements CSMA protocol. In this phase, a simple neighbor discovery protocol will be run to gather the information about list of one hop neighbor (OHN) and two hops neighbor (THN) for each node. All the sensor nodes will exchange the information among their neighbors. This list will be used in slot allocation mechanism. Figure 4 shows the flow chart of random phase process.

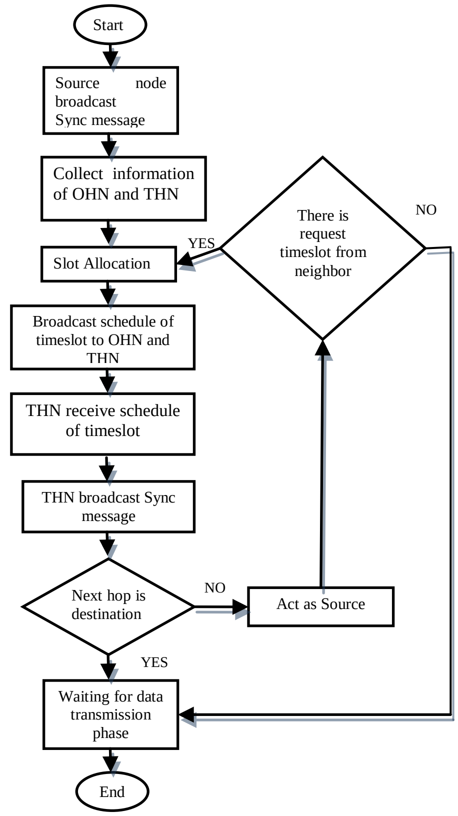


Figure 4 Flow chart for random phase process

3.2 Slot Allocation

Slot allocation for each sensor node will be done after neighbor discovery protocol. Source node will responsible to decide timeslot for its neighbor and broadcast the list of timeslot to its neighbor. The sensor node that outside coverage area of source node will select the nearest neighbor that already have a timeslot act as source node. Each sensor node will store the information about its one and two hops neighbor backward and forward in neighbor table. For example as shown in Figure 5, all the neighbor will be divide into different set which is SET A, B, D and E to ensure there is no other nodes within two-hops neighbor choose the same slot. The owner of the node is SET C. In our propose slot allocation, reuse timeslot will be used after two hops neighbor (the list of neighbor in SET D can reuse timeslot the neighbor in SET A). To avoid collision, the timeslot that used by neighbor in SET A, B, D and E cannot have same timeslot with SET C.

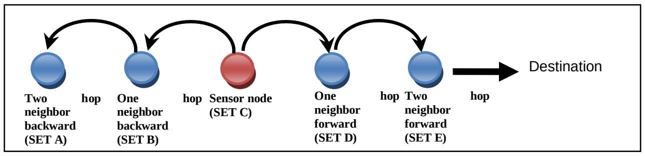


Figure 5 List of neighbor node

3.3 Data Transmission Phase

In the data transmission phase, TDMA protocol will applied first. The owner of the slot will transmit beacon at the beginning of the timeslot. The beacon consists of synchronization message to make sure that all node in the network synchronize with each other. Besides that, in the beacon message also indicate the status of the owner of the slot. If the owner has data to sent, it will use the slot to send the data, but if the owner did not have data to sent, it will allow its neighbor node to content to get the slot. The neighbor node will decide whether in TDMA mode or CSMA mode depends on level of contention in the network at that time. If the network in high contention level (HCL), the neighbor node will be in TDMA mode and wait for its own timeslot. But if the network in low contention level (LCL), the neighbor node can switch in CSMA mode and content with other node to get the slot. This feature gives opportunity to other node to used free slot and suitable for priority application usage because it can access the network when low contention happen in the network. The flow chart for transmission data phase process is shown in Figure 6.

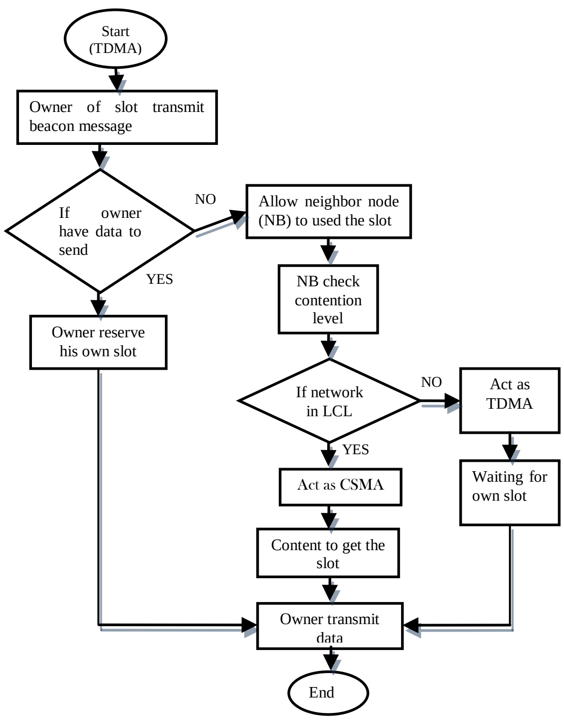


Figure 6 Flow chart in transmission data phase

4.0 SYSTEM MODEL DESCRIPTION

In multi-hop wireless sensor network, one or more sensor nodes are used to make connection from source to destination. WSN consists of sensor nodes that equipped with low power device that located in the certain area to perform various applications from low to high critical application. The position of the sensor nodes either in grid topology or distributed topology conform to limited range of coverage that support by hardware that are used [15]. In our protocol, we choose to implement distributed topology that consists of one source, one destination and 13 sensor nodes as shown in Figure 7.

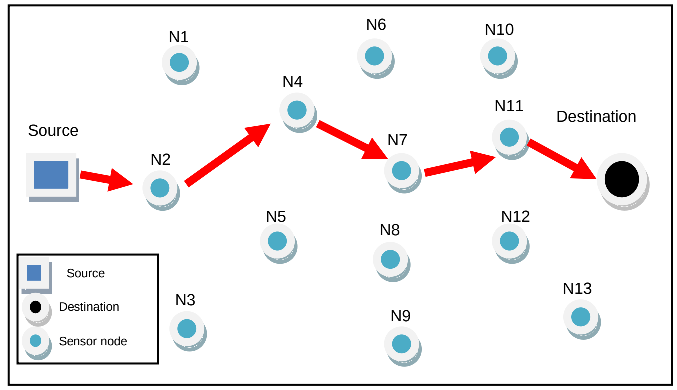


Figure 7 Proposed Distributed Topology

The sensor nodes in Figure 7 will be selected to do multi-hop connection and the selection of the forwarding node will be handle at network layer by using real time load distribution (RTLD) routing protocol[16]. The distributed topology are chosen to make sure that our propose protocol are not strict to same length (same position in the network) but can cope with topology changes when some of the sensor node are died (out of battery) or network hole happen. Table 1 shows the simulation parameters.

Table 1 Simulation parameters

Parameter	Value
Wireless Channel	IEEE802.15.4
Simulation Tool	NS2
Frequency	2.4Ghz
Data Rate	250kpbs
CSThresh	1.559e-11
RXThresh	3.652e-10
Communication range	8m-10m
Power transmission	1mw

5.0 PRELIMINARY RESULT

This section provides preliminary result for neighbor discovery protocol that implement in this proposed work. The simulation model that used based on the system model description that describe in section 4. Unslotted CSMA protocol in IEEE802.15.4 is used for neighbor discovery protocol. Source node will start broadcast beacon message to its one hop neighbors to gather its one hop neighbor list. Each sensor node in the network also broadcast beacon message to its neighbor and store the information in the neighbor table. Through this process, each sensor node not only gathers the information about its one hop neighbor but also two hops neighbor as shown in Figure 8.

6.0 CONCLUSION AND FUTURE WORKS

In this paper, we have proposed a hybrid MAC protocol design that can be used for priority application usage. Our proposed protocol was different from others because we are going to implement hybrid MAC in data transmission. Compared to other protocol, they only used TDMA in transmission of data. The transmission of the beacon at the beginning of slot is used to update synchronization time and neighbor table if there is a new node that enters the network at that time. These proposed features can increase channel utilization where all slot in the network will be fully utilized. Besides that, the probability of collision happen between owner and non owner of the slot will not be happen because non owner of the slot will not content of the slot if the owner has data to send. This also can decrease the energy consumption because the non owner of the slot only content of the channel if the owner has no data to send and the owner will go to sleep mode. For future work, we want to implement our proposed protocol in network simulation tool (NS2). Some analysis will be conducted to prove that our proposed protocol can improve network performance in term of channel utilization and energy consumption.

```
-----------------------------------------------------
NODE 0 (Source Node)
One hop neighbor(OHN) :  1 3 2
Two hop neighbor(THN) :  5 4
No of Neighbor = 5
-----------------------------------------------------
NODE 1
One hop neighbor(OHN) :  2 0 4
Two hop neighbor(THN) :  3 5 6 8 7
No of Neighbor = 8
-----------------------------------------------------
NODE 2
One hop neighbor(OHN) :  3 5 0 4 1
Two hop neighbor(THN) :  8 7 6
No of Neighbor = 8
-----------------------------------------------------
NODE 3
One hop neighbor(OHN) :  5 2 0
Two hop neighbor(THN) :  8 4 1 7
No of Neighbor = 7
-----------------------------------------------------
NODE 4
One hop neighbor(OHN) :  6 1 2 8 5 7
Two hop neighbor(THN) :  10 11 3 0 13 12 9
No of Neighbor = 13
-----------------------------------------------------
NODE 5
One hop neighbor(OHN) :  8 2 7 4 3
Two hop neighbor(THN) :  10 6 11 0 1 13 12 9
No of Neighbor = 13
-----------------------------------------------------
NODE 6
One hop neighbor(OHN) :  10 11 7 4
Two hop neighbor(THN) :  14 5 8 12 1 2
No of Neighbor = 10
-----------------------------------------------------
```

```
-----------------------------------------------------
NODE 7
One hop neighbor(OHN) :  10 6 5 8 11 4 12
Two hop neighbor(THN) :  14 2 13 9 3 1
No of Neighbor = 13
-----------------------------------------------------
NODE 8
One hop neighbor(OHN) :  5 7 4 13 12 9
Two hop neighbor(THN) :  2 10 6 11 14 3 1
No of Neighbor = 13
-----------------------------------------------------
NODE 9
One hop neighbor(OHN) :  8 13 12
Two hop neighbor(THN) :  5 11 7 4 14
No of Neighbor = 8
-----------------------------------------------------
NODE 10
One hop neighbor(OHN) :  6 11 14 7
Two hop neighbor(THN) :  5 8 4 12 13
No of Neighbor = 9
-----------------------------------------------------
NODE 11
One hop neighbor(OHN) :  14 6 7 12 10
Two hop neighbor(THN) :  5 8 4 13 9
No of Neighbor = 10
-----------------------------------------------------
NODE 12
One hop neighbor(OHN) :  11 14 9 8 13 7
Two hop neighbor(THN) :  10 5 6 4
No of Neighbor = 10
-----------------------------------------------------
NODE 13
One hop neighbor(OHN) :  12 14 9 8
Two hop neighbor(THN) :  10 11 5 7 4
No of Neighbor = 9
-----------------------------------------------------
NODE 14 (Destination Node)
One hop neighbor(OHN) :  10 11 13 12
Two hop neighbor(THN) :  6 7 9 8
No of Neighbor = 8
```

Figure 8 Result of neighbor discovery

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