

Synchronized Latency Secured MAC Protocol for PON Based Large Sensor Network

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Abstract— We have seen that the requirement of sensor nodes in a U-city is extremely high. To get the appropriate services from the sensor nodes of u-city we have to consider the delay, energy consumption and network size of each Wireless Sensor Network (WSN). Zigbee provides a possible solution to reduce the number of hops by dividing the whole sensor network into several clusters, but the latency is a prime limitation. We propose a Synchronized Latency Secured (Sync-LS) MAC protocol as a new protocol which will solve the latency problem by reducing the number of time frames requirement in the cluster while the energy consumption is nearly same as Zigbee. In addition to the Sync-LS MAC we are going to propose a Passive Optical Network (PON) based architecture to connect all the cluster heads with the Personal Area Network Coordinator (PANC). Here, the PANC acts as an Optical Line Terminal (OLT) and each cluster head acts as an individual Optical Network Unit (ONU). PON based architecture is a best solution of high bandwidth requirements with inexpensive and integrated broadband services to the users in a very efficient way. PON has sufficient bandwidth but to efficiently utilizing it a proper Dynamic Bandwidth Allocation (DBA) algorithm is required for bandwidth allocation among the ONUs. We have proposed a framework that classify the ONUs on the basis of service priority and allocate the bandwidth according to that priority. This framework is a combination of new Sync-LS MAC protocol for cluster based WSN with PON.

Keywords— Sync-LS MAC, PON, Wireless sensor network, OLT, ONUs

I. INTRODUCTION

As the diameter of the WSN based u-city and metropolitan area is becoming very large. Energy efficient and latency secured wireless communications are a challenging topic in low data rate WSN. In the conventional WSN a single PANC is used to manage the whole networks. In this case the number of hops is very high from the surface nodes to the PANC which requires large time delay. To maintain the energy efficiency the duty cycle of sensor nodes is reduced which is another factor to increase the latency in the network. By now, it has been understood that to overcome the energy consumption and latency problem together cluster based WSN is the optimized solution. In [1] a cluster based WSN is proposed where each cluster contains a coordinator and all sensor nodes of the cluster is connected with the coordinator

through a small number of hops and all the coordinators are connected to the PANC by Radio-over-Fiber (RoF) link. Even though cluster based network is able to reduce the network diameter still the latency is a main challenge in delay sensitive environments. Many researchers have proposed different MAC protocols to solve the latency problem with permissible energy consumption.

Zigbee is a well acceptable approach to implement the WSN which supports the number of time frames requirement is proportional to the number of hops as well as in S-MAC [2-3]. In DMAC[4] duty cycle is adjusted adaptively depending upon the traffic load but requirements of the time frames are also directly proportional to the number of hops. Adaptive S-MAC [5] reduces the latency by half than S-MAC and Zigbee since two hops transmission is executed in a time frame. In LE-MAC[6] up to 4 hops data transmission is executed in a single time frame but the extension of Carrier Sensing (CS) range is a dilemma of this protocol. To solve this latency problem an appropriate MAC protocol and cluster based WSN can be a good research issue where each cluster head will be connected by PON.

PON is an optical network that does not contain active elements between source and destination which is effectively reduced the requirements of active components and power consumption of the networks. It only contains passive optical components such as optical fiber, couplers, splices, and splitters. A PON can be deployed in several topologies, e.g., tree, ring, or bus[7]. PON is a point-to-multipoint optical network it minimizes the fiber deployment, provides high bandwidth, and allows for long distance between the central office and customer premises.

In this paper, we propose a Synchronized Latency Secured (Sync-LS) MAC as a new protocol for PON based WSN. The main objective of this protocol is to reduce the requirements of the time frame to only one which is immaterial to the number of hops exists in the network. This protocol considers inside a cluster while the cluster heads will be connected to the central office by PON system. The analysis could be extended to assign an effective bandwidth allocation and node registration algorithm.

The rest of the paper is organised as follows. The background study of the MAC protocol and PON is investigated in Section 2, followed by an investigation of the proposed Sync-LS and PON structure for WSN in Section 3. In

Section 4 we evaluate the system performance by simulation and theoretical analysis. Finally, the conclusions are drawn in Section 5.

II. BACKGROUND STUDY

A. MAC Protocol

Sensor nodes are small battery powered devices, efficient power management is very important for longer life of the nodes. MAC protocols play a vital role for efficient data transmission and collision avoidance in a wireless communication system. Different MAC protocols have proposed to reduce latency as well as energy consumption. In many sensor network applications, nodes are in idle for a long time if no sensing event happens[3]. Given the fact that data rate in the sensor network is very low, so to keep all the nodes listening all the times is unnecessary. Periodic sleep and listen is the most popular way to save the energy consumption of a network.

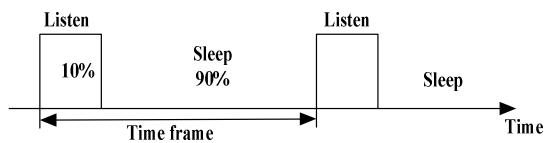


Figure 1. Periodic listen and sleep

From Figure 1 it is clear that the nodes in the networks remain in active state only for the 10% time and rest of the 90% time in the sleep state. So 90% energy savings can be achieved by using this protocol than the conventional protocols. The duration of time for listening and sleeping can be selected according to different application environments.

Latency is another prime factor among the factors concern in MAC protocol of WSN. Typical communication patterns in data aggregation involve multiple data sources and one data sink. The source nodes communicate to sink by forming a multihop network. In this regard, efficient routing in such multihop network becomes crucial in achieving latency efficiency as well as energy consumption. As the diameter of WSN is increasing, the numbers of intermediate hops are also increasing. Many MAC protocols including Zigbee support single hop transmission in a time frame. That is why delay in the networks increase proportionally with the hops number. Figure 2 shows the 4 hops network operation which requires 4 time frames [2], [3]. To overcome this problem adaptive S-MAC [5] is proposed which support two hops transmission in a time frame. This scheme reduces latency in alternate hops, if the hop number in the network is more than two then this scheme also suffers from large time delay. Another useful approach for reducing the requirements of time frame in the network is LE-MAC[6] which support up to 4 hops transmission in single time frame. If the total number of hops in a network is more than 4 then it requires another time frame and network suffers from latency problem. Adaptive S-MAC and LE-MAC has a limitation of CS range and synchronised SYNC signal transmission which is impractical.

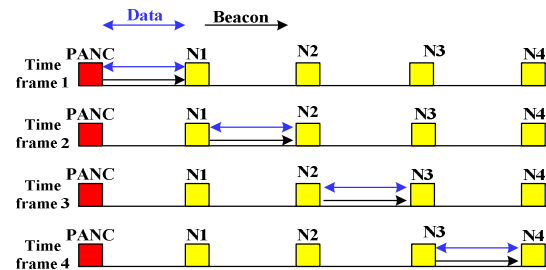


Figure 2. Operation of Zigbee

B. Passive Optical Networks

A PON is a backbone network which does not require any active element in the network; it also reduces the deployment of optical fibers. PON is normally seen in tree like topology, where OLT will be at the root and ONUs will be at the leaf side [8]. Multiple ONUs are connecting to the OLT through 1:N splitter/combiner. Data transmission from OLT to ONUs is called downstream traffic which is broadcast in nature because data is sent by an OLT and received by all ONUs as shown in Figure 3. In the upstream direction the ONUs collect data from different end users and store that data into its buffer. When data is collected from the end users these ONUs send a request to the OLT. In the upstream direction ONUs cannot send data to other ONUs as shown in Figure 4.

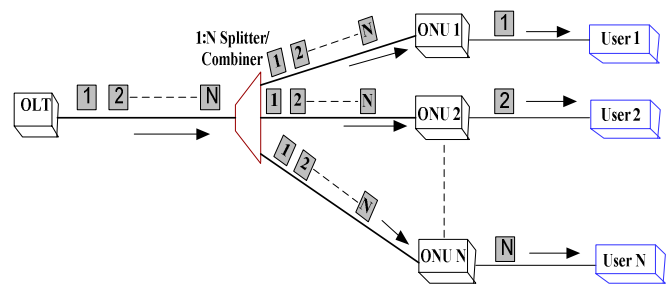


Figure 3. Downstream traffic in PON

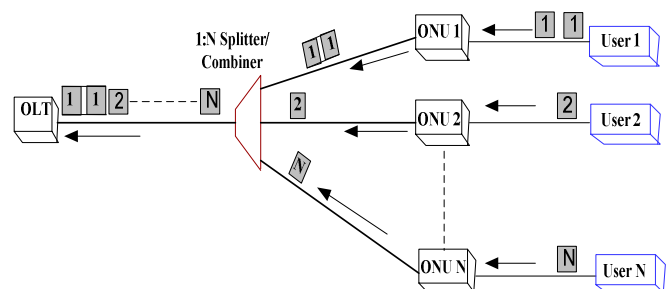


Figure 4. Upstream traffic in PON

In upstream direction, the ONUs should share the channel capacity and resources. So there is a possibility of collision in the upstream direction. To overcome this problem many contribution have been made so far, in which TDM is currently considered as the cost effective solution. WDM mechanism is being considered as alternative solution of TDM but these solution is not effective in term of cost[9].

III. SYNC-LS MAC AND PON STRUCTURE FOR WSN

The main objective of the proposed Sync-LS MAC protocol is to reduce the time delay, avoid collision, and minimize the idle listening. To extend the WSN we also proposed clustering based networks and connecting the cluster head through PON scheme where cluster heads are considered as ONUs and sensor nodes as end users.

A. Sync-LS MAC protocol

In this scheme, the time frame is divided by two parts; first part is used for forward data transmission called forward time frame and second part is used for reverse data transmission called reverse time frame. In the forward time frame coordinator node starts transmission of beacon and forward data and successively transmits up to the end node of the transmission path. After transmission of forward data every node immediately goes to the sleep mode to save energy and set up a wakeup timer for reverse transmission. Figure 5 shows the operation of Sync-LS MAC protocol where at the end of forward data transmission sleep time is provided before the starting of reverse time frame. In the reverse time frame parent node sends the beacon to its children nodes and receives the reverse data and children nodes switch to sleep mode, this process is maintained up to the coordinator. In the Figure 5 it is seen that node N3 sends beacon to its child node N4 and receives the reverse data.

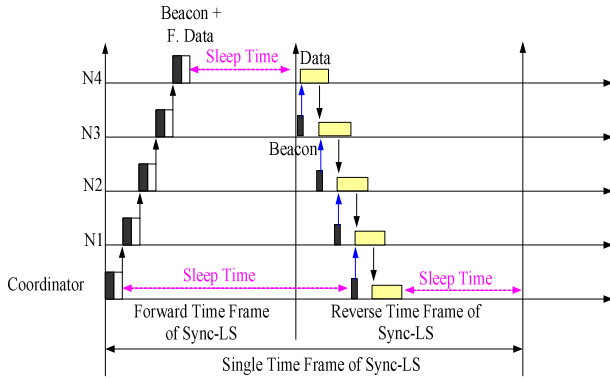


Figure 5. Operation of Sync-LS

In the reverse time frame beacon generation time is fixed for each parent node which is maintained by wakeup timer. The beacon generation time of each parent node is explained by the following expression:

$$t_{br}(n-k) = t_{bf}(n-k) + t_{margin} + (k-1)\Delta t_r + k \times \Delta t_f \quad (1)$$

where, t_{br} is reverse beacon generation time, n is the maximum hop number, k is hop distance from edge node, t_{bf} is forward beacon time, t_{margin} is additional sleep time before the reverse time frame, Δt_r is the time interval between consecutive two reverse beacons, and Δt_f is the time interval between consecutive two forward beacons.

B. Structure of PON-Based Sensor Network

Figure 6 shows the network architecture of proposed PON based WSN with forward data and beacon broadcasting in downstream traffic. Here, the OLT act as PANC at root side of the tree topology and ONUs act as coordinators of WSN clusters at leaf side. The beacon and forward data itself has some time delay depending on the number of hop distance from the coordinator which is shown in the forward time frame in Figure 5.

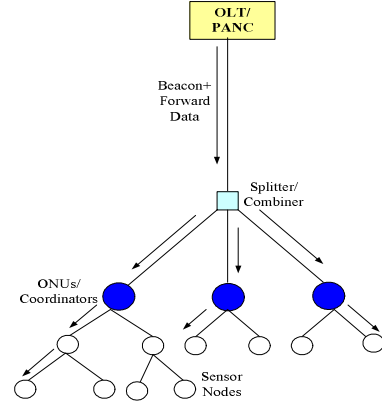


Figure 6. Forward data transmission in PON

Figure 7 represents the reverse data transmission from the sink sensor nodes to the PANC. In Figure 7 (a) it is found that at reverse time frame the nearest parent nodes of the surface nodes send the beacon signal to activate its children nodes and receive the reverse data. Since the beacon transmission time from parent node toward the children nodes is distinct it is called synchronized latency secured MAC protocol. Figure 7 (b) represents the reverse data transmission between the coordinators and its nearest children nodes where beacon is sent by the coordinators. After receiving the reverse data by the coordinators a request message is sent to the OLT for granting the required timeslot size. The OLT replies to the ONUs with allocated time slot size which is according to the priority and requirement of the ONUs. Figure 7 (c) shows the reverse data transmission between the ONUs and OLT.

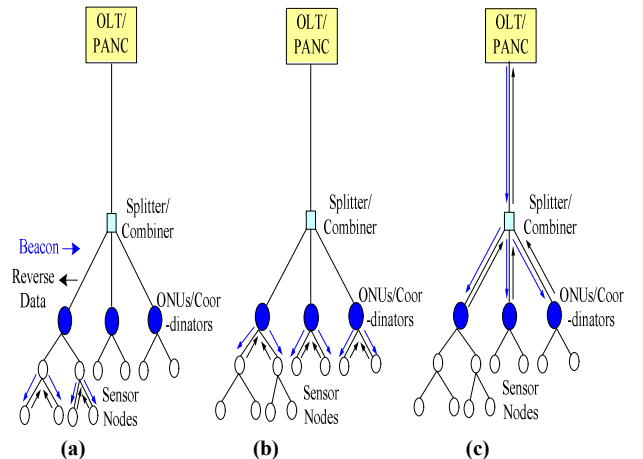


Figure 7. Reverse data transmission; (a) data transmission from surface nodes to intermediate parent nodes, (b) Data transmission from parent nodes to ONUs, (c) Data transmission from ONUs to OLT

C. DBA of PON for Efficient BW Utilization

Nowadays almost all scheduling algorithms are dynamic in nature for proper utilization of bandwidth and other network resources. Similarly DBA is also important in PONs to avoid collision, packet delay, queuing delay, and packet loss in the upstream data transmission. In DBA the assigned time slot length varies according to the dynamic traffic, so there is less possibility of bandwidth wastage. In case of typical Static Bandwidth Allocation (SBA) scheme the time slot is fixed for each ONU. If an ONU has no data to transmit then the allocated time slot will be wastage, thus resulting in an increased delay for all the data buffered in other ONUs. The main advantage of SBA is easy to implement.

Here, we propose a bandwidth management scheme which will work with our algorithm, called limited service to tackle the DBA issue for PON based WSN. In limited service algorithm OLT assigns the bandwidth to the ONUs according to their demand which is restricted by the upper bounding[7]. As we know that the sensor nodes generate both emergency and nonemergency data traffic. The emergency data traffic should be provided the highest priority than nonemergency data traffic. To implement this type of priority we proposed that each ONU should have two queues; one is priority queue and another is best effort queue. First, the ONUs will be allowed to transmit data from the priority queue then the remaining time slot will be occupied by the best effort queued data. If the allocated time slot is not enough to transmit all the existing queued data then the best effort queued data will wait for the next transmission window.

D. Even Distribution Algorithm of Sensor Nodes

Even distribution of sensor nodes is a new term used in this study which is very important for clustering based WSN to balance the number of sensor nodes among the clusters. To maintain the network size within a certain limit hop number is used as the main limiting factor. Figure 8 shows the flow chart of the proposed algorithm where H_{lim} is the maximum hop number.

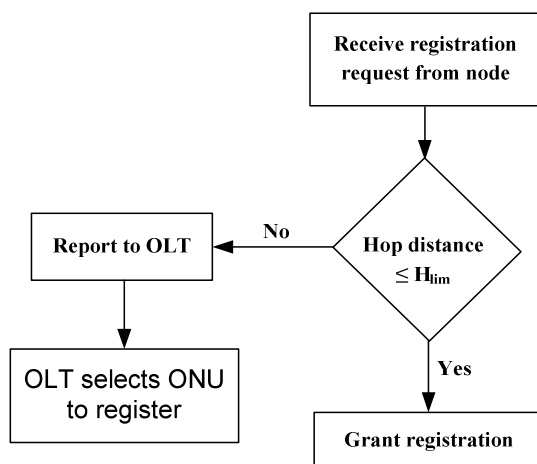


Figure 8. Registration algorithm of a new sensor node

The H_{lim} larger than 3 is not allowed to make registration in the proposed algorithm as shown in Figure 9. In case of special consideration OLT can handle the situation and can allow the nodes to make registration to their nearest ONU. After registration of node to any ONU the OLT must update its information.

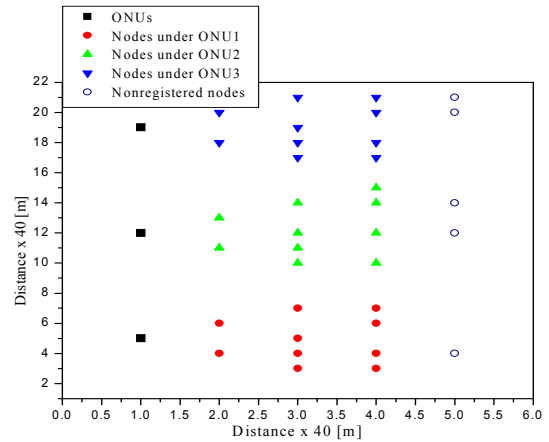


Figure 9. Node distribution scenario

According to this algorithm unlimited number of nodes can not be included in a cluster. To meet the increase demands of new nodes in the network this algorithm recommends to increase the number of ONUs instead of the number of nodes of the existing ONUs.

IV. PERFORMANCE EVALUATION

Latency and energy consumption are calculated using C++ for various types of protocol in addition to the Sync-LS. To calculate latency random data packet generation time is considered for 10 hops unsymmetrical cluster shown in Figure 10. It is assumed that all the sensor nodes generate 100 bytes data packet in each time frame, which are transmitted toward a single coordinator. Time frame is set to 1 sec and duty cycle is assumed to be 10% for every node in the latency and energy calculation. Simulations are done for 10 seconds and the results are used to calculate the average.

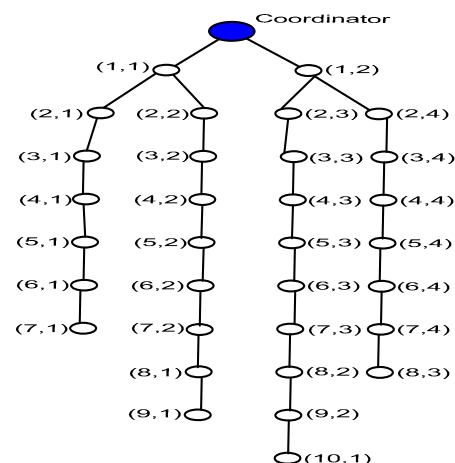


Figure 10. Network model of simulation

Figure 11 shows that latency of Sync-LS is much smaller than those of Zigbee and adaptive S-MAC. The latency of LE-MAC is similar to Sync-LS up to 4 hops, but, the difference becomes larger as the hop number is increased. In LE-MAC only 4-hop transmission is possible in a single time frame, so additional time frame is required for each 4 hops. In Zigbee and Sync-LS latency is increased linearly with the number of hops. The additional latency required in Zigbee is due to the required number of time frames which is directly proportional to the number of hops in the network, but Sync-LS MAC requires only one time frame for all hops in the cluster.

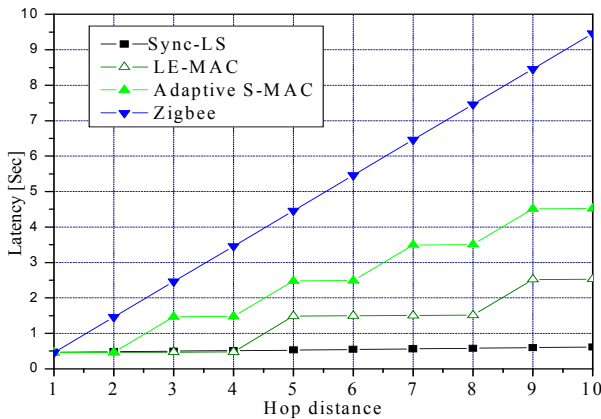


Figure 11. Comparison of average latency

Figure 12 shows the comparison of energy consumption when 100-byte data packets are generated by each node in every time frame. It is clear that Sync-LS MAC consumes only a slight more energy compared to Zigbee in 10-hop unsymmetrical network shown in Figure 10.

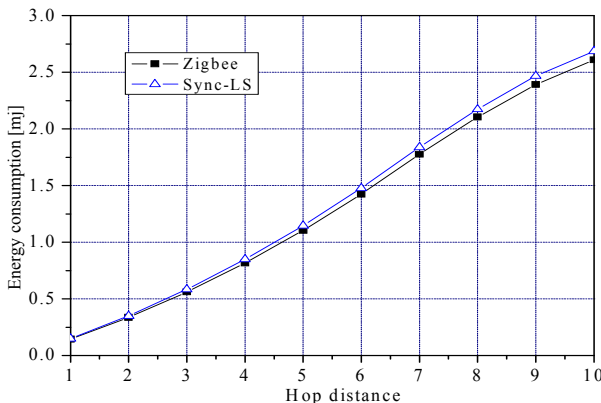


Figure 12. Comparison of energy consumption for the example network in Fig. 10

From the comparative analysis it is observed that if the data traffic in the network is small then additional sleep time can be provided between forward and reverse data transmission in Sync-LS MAC while in Zigbee reverse data must be transferred immediately after the forward data. The connection of high speed PON system with the coordinators is also capable to solve the data congestion problem which is very important for large sensor networks.

V. CONCLUSIONS

In this paper, we have discussed the PON based WSN architecture and Sync-LS as a new MAC protocol which can effectively reduced the latency. Since only one time frame is required for reverse transmission which has no restriction of hops number in the cluster, the proposed scheme can be applied to time-sensitive applications. We also have investigated dynamic bandwidth allocation issue of the upstream channel using priority and best effort data traffic. That is why emergency data will not suffer any time delay problem. The proposed even distribution algorithm of sensor nodes among clusters will help to avoid data congestion and load unbalance problem in upstream channel over PON.

An interesting future research would be to investigate how the proposed Sync-LS MAC responds to huge data packet. Since the main limitation of Sync-LS is the requirement of large queue size in the nodes near coordinators if the network size is very large.

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