A cluster-based hybrid broadcasting mechanism for quorum systems with power management and delay constraint in the MAC sub-layer

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Abstract

Quorum based asynchronous protocols -which guarantee overlap between two asynchronous neighbor nodes at least in a time interval for data transmission- have serious problems in broadcasting packets because nodes have no information about their neighbors' schedules. Synchronous protocols need to synchronize the whole network that leads to less delay but more energy consumption. In contrast, asynchronous protocols need no clock synchronization and save more energy but impose high delays. This article proposes a hybrid mechanism for broadcasting packets which uses the advantages of both synchronous and asynchronous protocols to solve the broadcasting problem in the quorum systems. The mechanism is cluster-based, that is, it uses an asynchronous protocol for communication between cluster-heads and a synchronous protocol for connecting a cluster-head to its members in a cluster. Simulation results indicate that compared with other methods, the mechanism suggested in this paper improves the rate of power saving and end to end delay.

Keywords: power management; quorum systems; broadcasting.

1. Introduction

Power management in wireless networks has a particular significance especially in wireless sensor networks because of their unique applications and possibility of deployment in inaccessible areas. Wireless sensor networks have restrictions in replacing power supply (battery) and dead sensor nodes. Thus, increasing networks lifetime with the focus on power saving and delay concepts are the main goals in proposing a new protocol in this field. Different protocols are needed by different networks according to their applications. Hence, providing a comprehensive approach to all networks with various applications is impossible.

Power management techniques are divided into two main groups: synchronous and asynchronous protocols.

- Synchronous protocols: These protocols need time synchronization and all nodes in a network are synchronized with its clock. Nodes are aware of their neighbors' schedules and data transmission is done according to these schedule tables. In all synchronous methods, broadcasting packets are easily possible. Time synchronization in a network leads to less delay in data dispatching and more power consumption. Because of this drawback asynchronous methods have been devised to save power.

- Asynchronous protocols: In contrary to synchronous protocols, asynchronous protocols do not need any time synchronization. Quorum-based systems are known as important asynchronous protocols which ensure overlaps at least in a time interval with adjacent nodes to exchange data.

Various quorum systems have been proposed for different applications. In comparison with synchronous protocols, these protocols save considerable amounts of power but impose a high delay to networks. There is a tradeoff between power consumption and delay in wireless networks, that is, an improvement in one leads to the destruction in another.

Dispatching of broadcasting packets in asynchronous protocols is considered as a serious problem because nodes are not aware of neighbors sleep/awake schedules, and thus broadcasting packets are associated with a high delay. One of the methods that have been proposed for broadcasting in quorum systems is based on the Chinese Reminder Theorem (CRT-MAC) which is not applicable to dense sensor networks due to the high delay.

In this regard, this paper suggests a hybrid approach to solve the broadcasting problem in quorum systems using the advantages of both synchronous and asynchronous protocols in order to improve power saving and end to end delay. In this method, when there is a broadcasting packet, the network will be clustered and a cluster-head will be determined for each cluster. Dispatching of the broadcasting packet is done in two phases: first the broadcasting packet is sent to all cluster-heads by using an asynchronous protocol. Then cluster-heads will be synchronized with their members individually in each cluster. In the second phase cluster-heads will send the broadcasting packet to their own members via a synchronous protocol.

The rest of the paper is organized as follows. In section 2, the related works are reviewed. Specifically, in subsection 2.1 the most important synchronous protocols and in 2.2 asynchronous protocols, especially quorum systems are discussed. Some available broadcasting methods are presented in section 3. Section 4 and its subsections are devoted to the description of the proposed mechanism. The evaluation of the proposed mechanism is provided in section 5 and finally results are reported in section 6.

2. Related works

2.1. Synchronous protocols

IEEE 802-11 PSM is an important synchronous protocol in wireless networks, which considers two power modes in power management [1]:

Active Mode (AM): In this mode, sensor nodes' radios are always active and can monitor transmitting activities in the network. Thus wireless sensor nodes can communicate with each other immediately. Since power consumption in the idle mode is approximately the same as the received mode, a large amount of power is consumed in the idle mode.

Power Saving Mode (PSM): The goal of this mode is to reduce power consumption in the idle monitoring. The performance of IEEE 802-11 PSM is illustrated in Figure 1.

Network card has two situations in this protocol: Active/Inactive. In the active mode, a node is ready for sending or receiving a packet but in the inactive mode it can't communicate with other nodes. In this protocol, the time axis is divided into equal length beacon intervals (BI). Each beacon interval begins with a short window called ATIM (Ad-hoc Traffic Indication Message), and all nodes are awake in this window. In each BI, all nodes are synchronized and at first try to send their beacon packets. Beacon packet is a control packet that is used for synchronizing nodes together. There is no central coordination agent in wireless sensor networks, therefore all nodes want to send their beacons. If all nodes are in each other's board, dispatching a beacon packet from one node will synchronize the network. After sending the beacon, ATIM packets should be transmitted. There is no data in ATIM packets and their aim is to inform destination nodes to wait for data. If a node receives this packet and its address does not match with the packet's

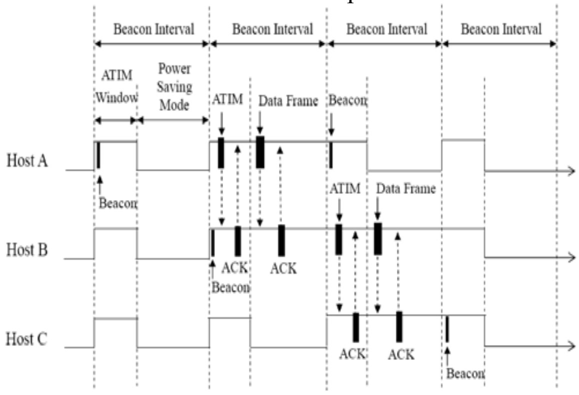

Fig. 1. Structure of IEEE 802-11 PSM

destination address, it can go to the inactive mode until the next beacon interval, but if the packet's destination address matches with the node's ID, it must send an acknowledgment packet and remain active up to the end of BI. In IEEE 802-11 PSM, all nodes should send their beacon packets since they have not received any beacon packets from the neighbor nodes. If a beacon packet is received by a node, it can be used to estimate the duration of the transmitter awake time and to determine the arrival of the ATIM window. In IEEE 802-11 PSM, single-hop networks which ensure all wireless nodes in the PS mode can wake up simultaneously in their ATIM window to synchronize their clock cycles by the TSF (Time Synchronization Function). Wireless sensor networks are considered as multi-hop networks due to their node density, thus routing and synchronization issues should be discussed for them. Problems arise in a multi-hop network when some nodes are not successful in receiving the beacon packet that is dispatched by a node which is not in their radio board. Consequently, they may begin to dispatch their own beacon packets, and synchronization done individually may lead to the network partitioning.

When network scale is large, global clock synchronization is very costly and complicated. Clock drifting and improper synchronization are, therefore, the major problems of multi-hop wireless networks.

2.2. Asynchronous protocols

Asynchronous protocols are provided to solve the problems of synchronization in multi-hop networks such as wireless sensor networks. As there is no need to clock synchronization in these protocols, a considerable amount of power is saved. Quorum based systems can be considered as the most common asynchronous protocols. The first power saving protocol based on the grid quorum system was proposed in [2]. Then other quorum based protocols were developed for different applications; Grid, Torus, QEC, AQEC and cyclic are quorum based systems [3], [5], [6], [7], [8]. In these systems, sleep/awake periods are set in a way that ensure an overlap with adjacent node for data transmitting.

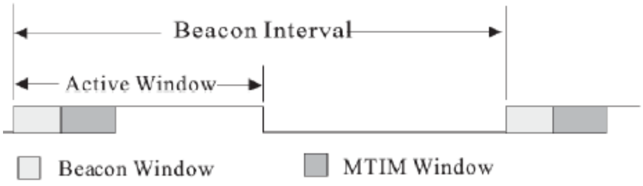

Fig. 2. Structure of a BI in the quorum interval

In QBP, the time axis is divided into intervals which are called quorum intervals QI with each QI containing *n* equal length periods. Each of these periods in QI is a beacon interval (BI) which is divided into three periods. There is a beacon window at the beginning of each BI, in which the beacon packet is dispatched. A beacon packet contains some general data such as node address and its timestamp. The second window in the BI is called MTIM (Multi-hop Traffic Indication Message) in which a node is waiting to receive MTIM packets from other nodes. The third part is devoted to sending and receiving and nodes can transmit data in this window. Figure 2 shows the structure of a BI in the quorum interval [2].

Power management protocols based on quorums in multi-hop networks utilize the concept of quorum systems in order to save more power. A quorum system is a group of sets in which intersections of each two sets are non-empty. All of quorum systems are not used in saving energy. These systems should have the rotation closure property to ensure the overlap of two active neighbors when nodes are asynchronous. In order to describe this property, first power management concepts in the quorum systems are explained below.

In QPS protocols, there is a universal set $U = \{0, 1, \ldots, n\text{-}1\}, n \geq 2$, which shows the consecutive beacon intervals of wireless nodes where *n* is the size of the quorum system.

The goal is to define quorum system *Q* under *U*, which contains non-empty subsets [3]. Each subset is called quorum and nodes can select one of these quorums as their active intervals. Each node is fully awake in its quorum interval and sends beacon packets at the beginning of each BI. Quorum system *Q* should guarantee two asynchronous neighbor nodes to receive each other's beacon in their quorum interval.

Definition 1: If *i* is a non-negative integer and *H* is a quorum in quorum system *Q* under $U = \{0, 1, \ldots, n-1\}, n \geq 2,$ the rotation property is explained as follows [3]:

$$rotate(H, i) = \{(j + i)\ mod\ n \mid j \in H\} \quad (1)$$

Definition 2: Quorum system Q under $U = \{0, 1, \ldots, n-1\},\ n \geq 2$ has the closure rotation property if the following relation is satisfied:

$$\forall G, H \in Q, i \in \{0,1, \ldots, n-1\}:$$
$$G \cap rotate(H, i) \neq \emptyset \quad (2)$$

Theorem 1: If Q is a quorum system satisfying the rotation closure property, Q will be a solution to the QPS problem. Its proof is in [3] in detail.

The quorum system used in the mechanism developed in this paper is the cyclic quorum system. In these systems [8], [9] definition of the quorum system is based on difference sets. A difference set under Z_n is defined as follows:

$$D_n = \{d_1, d_2, \ldots, d_k\} \mid \forall e \neq 0 \Rightarrow$$
$$\exists d_i, d_j \in D\ \ that\ \ \ d_i - d_j\ = e\ mod\ n \quad (3)$$
$$1 \leq i, j \leq k$$

In order to have a cyclic quorum system with size *n* and a difference set D_n under Z_n, the cyclic quorum system defined by *D* is $Q = \{G_1, G_2, \ldots, G_n\}$ where G_i is [3]:

$$G_i = \{d_1 + i, d_2 + i, \ldots, d_k + i\}(mod\ n) \quad (4)$$
$$i = 0, \ldots, n-1$$

Here *i* is the offset and the difference set can be shifted by this arbitrary number. If Q satisfies these conditions, it would be a cyclic quorum system. In other words, it is guaranteed that all nodes overlap with their neighbours in their active intervals if they arbitrarily choose one of G_is for their active intervals. The advantage of the cyclic quorum system over other quorum systems is its effective power saving and minimum awake time.

3. Broadcasting mechanisms in quorum systems

A major problem with the power management of quorum systems is the transmission of broadcasting packets. Network upper layers' default is that MAC sub-layer can send requests or data to all nodes via broadcasting packets simultaneously. Power management concepts in the quorum systems make all nodes not to be active contemporarily so that packets are not delivered to all nodes at once. Some mechanisms are described below.

3.1. Retransmission

In this method [2], [3], [5], a broadcasting packet is sent several times until the sender node makes sure that all neighbours have received the packet. This is necessary because neighbour nodes are awake in different times and retransmission should cover all nodes. The sender node remains awake in the consecutive beacon intervals to assure that retransmission of the broadcasting packet is sufficient. The amount of power used in the sender is not negligible. In large quorum systems which save much more power, power consumption increases in the process of transmitting the broadcasting packet. In the worst case a sender has to remain awake in all beacon intervals to retransmit a

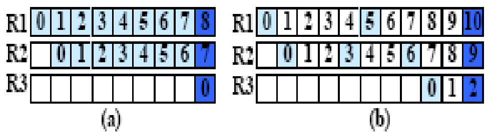

Fig. 3. The comparison of Busy waiting and CRT-MAC approaches for sending multicast messages

3.2. Busy Waiting

This method is a simple mechanism that enforces neighbour nodes to be active simultaneously when a broadcast packet wants to be sent. In this mechanism, the sender makes all receivers aware of the broadcasting packet and all nodes would remain awake to receive it. The receivers which enter the busy waiting mode earlier than others consume more power in the idle mode to deliver the broadcasting packet. The worst case is when all neighbour nodes except one are in the busy waiting mode and the sender waits for the last node to awake.

3.3. CRT-MAC

A multicast method is presented based on the Chinese Reminder Theorem (CRT-MAC) [4]. In this mechanism, a multicast packet sender devotes m none-negative integer numbers, which are relatively pairwise prime, to m receivers when they are awake as their active intervals. It means that each node after receiving the number will awake in its multiples. The integer numbers are in the descending order. The highest prime number devotes to the node that awakes first, and thus its wakeup frequencies decrease. Based on the Chinese Reminder Theorem, it is proved all m receivers would be awake contemporarily in one beacon interval and the sender dispatches its multicast packet in this interval. The advantage of this method over the busy waiting mechanism is that receivers would not be awake in all intervals when they would be aware of the multicast packet. They would be awake just when the packet is delivered. A node which is informed earlier would be awake with a lower frequency, which leads to more energy saving than busy waiting as shown in Figure 3. This mechanism works well when there are a few receivers (e.g. 3 receivers). A drawback to this mechanism is that when the number of receivers increases, the delay of dispatching packets increases too.

3.4. The BQPS mechanism

BQPS is a mechanism for broadcasting packets in the cyclic quorum-based power saving protocols. Here, beacon intervals are split into two intervals: quorum and non-quorum intervals. Quorum intervals start with a beacon window. After the beacon window, the node remains active broadcasting packet
(in the monitor mode) for the rest of the beacon interval. Non-quorum intervals start with a BTIM window. After the BTIM (Broadcast Traffic Indication Message) window, the

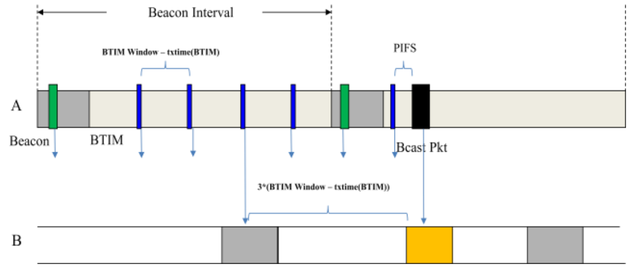

Fig. 4. The BQPS mechanism

node goes to the PS mode if it has no packets to send or receive. In the BTIM window, the node is awake and listens to the media to receive BTIM packets. A BTIM packet is a control packet in the MAC sub-layer which includes source address, destination address (MAC-Broadcast) and BTIM number. In BQPS, the transmitter informs all the neighbours of the broadcasting packet by sending BTIM packets.

When the transmitter intends to send a broadcasting packet, first it sends n BTIM packets in one beacon interval. The time interval between every two BTIM transmissions (*t)* is defined as follows [10]:

$$t = BTIM\ Window\ Size - txtime(BTIM) \quad (5)$$

and,

$$n = \left\lfloor \frac{Beacon\ Interval\ Size}{BTIM\ Window\ Size - txtime(pkt)} \right\rfloor + 1 \quad (6)$$

where *txtime(pkt)* equals to the time of sending a packet. Based on the results, the BTIM packet's size is 4.7 ms. IEEE 802-11 DCF is used here to prevent the simultaneous transmission of BTIM packets.

Theorem 1: BQPS guarantees that all neighbors receive at least one BTIM packet in their BTIM window or quorum interval if no collision occurs. Its proof is provided in detail in [10]. Figure 4 shows the BQPS mechanism.

When the receiver node receives a BTIM packet, based on the packet number and its reception time, it estimates the reception time of the broadcasting packet and sets a timer. After the timer expires, the receiver wakes up and delivers the broadcasting packet. The advantage of BQPS is that the number of transmitted BTIM packets and the delay of broadcasting packet are independent from the number of neighbours and the size of the quorum system. Therefore, when there is a great deal of neighbours around a node, a certain number of packets are needed to inform them about the broadcasting packet. Compared with other mechanisms, this mechanism decreases the delay of broadcasting packets and improves the throughput of the power saving mechanisms, especially when there is a high number of nodes in the network or the size of the quorum system is very large and power saving is higher. It is also demonstrated that this mechanism increases the network's lifetime but does not increase energy consumption. Compared to other mechanisms such as retransmission and busy waiting, this mechanism has a better performance even when the network density is high or the percentage of the active intervals of nodes diminishes.

Based on the study, the broadcasting mechanisms in the asynchronous protocols impose a high delay on networks. Having considered the characteristics of different methods, this paper attempts to develop a hybrid mechanism of synchronous and asynchronous protocols, which improves power saving and end to end delay of networks. The mechanism suggested is a hybrid mechanism based on power saving that is abbreviated to HBPS.

4. The proposed HBPS mechanism

4.1. Network Clustering

The cluster-based mechanism is proposed for broadcasting packets in the quorum systems. LEACH [11], a cluster-based protocol which is used in the proposed mechanism, minimizes power loss in sensor networks. It randomly selects sensor nodes as cluster-heads, thus in communication with the base station power loss would be distributed among all sensor nodes in the network. In this protocol, time is divided into the sections of equal length called rounds. Each round is split into two phases: the set-up phase and the steady state phase. During the set-up phase, clusters are created and cluster-heads are selected. The steady-state phase which is for data transmission is comprised of some time frames. In each frame, members of the clusters send their data to their defined cluster-heads and the cluster-heads send the received data to a base station (BS) at the end of each round. The steady-state phase is longer than the set-up phase to minimize the overhead. During the set-up phase, each sensor node chooses a random number between 0 and 1. If this random number is lower than a certain threshold, the sensor node is selected as a cluster-head. After all cluster-heads are selected, they broadcast an advertisement message to the entire network declaring that they are cluster-heads. Every sensor node receiving this message decides which cluster it can join based on the signal power of the received message. Therefore, sensor nodes send join requests to the proper cluster-heads and then clusters are formed. After that, each cluster-head allocates a time slot to its members to send their data through TDMA. During the steady-state phase, sensor nodes sense their environment in each cluster and then pass their data to the cluster-head. Afterwards, cluster-heads send the aggregate data to the base station and thus a round is finished. For beginning another round, the network enters the set-up phase once more and the cluster-heads are reselected and this process continues till all nodes are selected as a cluster-head at least once. Since choosing the cluster-heads in LEACH is distributed, each node has only one opportunity to be a cluster-head, and in turn it is certain that all nodes will be chosen as a cluster-head at least once. Results of LEACH indicate that if the number of clusters would be 5% of all nodes, the best results will be achieved. But since wireless sensor networks have many nodes and the synchronous power saving mechanism is used inside clusters, it is necessary to synchronize the nodes' clocks. Thus, to avoid more complexity of the synchronization, it is better to choose a high number of clusters to have fewer cluster members so that inside of the clusters could be considered as a single-hop structure. Therefore, clustering solves the problem of facing multi-hop networks. The optimal number of clusters required changes according to the number of nodes in a network. The number of clusters depends on how many nodes we would like to have as members in each cluster.

$$\frac{n}{m} = k \qquad \begin{array}{l} n: Number\ of\ Nodes \\ m: Approximate\ Number\ of\ members \\ k: Number\ of\ clusters \end{array} \tag{7}$$

4.2. Inter-cluster and intra-cluster protocols

IEEE 802-11 PSM is one of the most important protocols in the synchronous power-saving protocols that outperforms other protocols in terms of energy consumption and delay. Thus, it is chosen as the synchronous communicative protocol inside the clusters. Synchronizing the nodes is easier when the clusters are single-hop and have few members. It should be noticed that in the proposed mechanism we do not discuss synchronization methods and their relevant problems in multi-hop networks since it is assumed that nodes are synchronous inside the clusters.

Since the main approach of this article is to present a broadcasting mechanism for the quorum systems, the asynchronous protocol for connecting the cluster-heads is chosen among the quorum-based power saving protocols. The mechanism considering the problem of broadcasting transmission in the quorum systems is BQPS [10], which is implemented based on ACQ (Adaptive Cyclic Quorum) [6]. As a result, BQPS is chosen as the communicative mechanism among cluster-heads. Since sending data packets is different from sending broadcasting packets in BQPS, HBPS is suggested only for broadcasting packets.

4.3. Beacon intervals structure

Beacon intervals for cluster-heads and their members are different in the HBPS mechanism. The beacon interval for cluster-heads is split into two groups: quorum and non-quorum intervals. If a cluster-head receives a broadcasting packet, it needs to stay awake in its next beacon interval to send the packet, whether its next beacon interval be quorum or non-quorum. So the cluster-heads' awake beacon intervals for synchronizing with members and packet transmission would be like a quorum interval. As illustrated in Figure 5, nodes are fully awake in the quorum intervals. At the beginning of the quorum interval, there is a beacon window and then there are MTIM and data windows, respectively. In the communication of cluster-heads, the MTIM window is non-functional, but it is necessary for the communication between cluster-heads and their members.

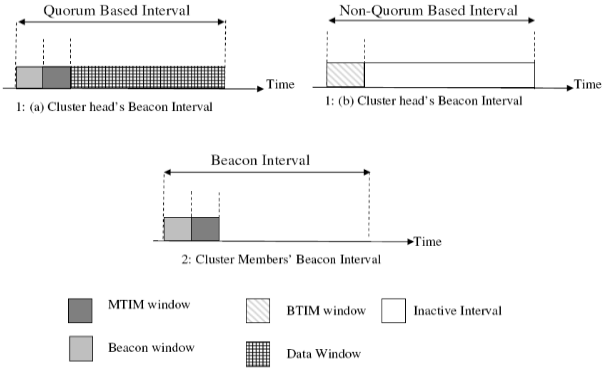

Fig. 5. Structure of beacon intervals, 1: (a) & (b) for cluster heads, 2: for cluster members

Cluster-heads pursue two goals in the awake quorum intervals: 1) neighbour discovering by increasing time for listening to media in the data window as well as data transmission. 2) Informing neighbours of their presence by sending the beacon packet in the beacon window. Non-quorum intervals in the cluster-heads begin with the BTIM window and then the node sleeps. The beacon interval for the cluster members is in accordance with IEEE 802.11 PSM. Since the cluster members need to be synchronous with their respective cluster-heads, the time synchronization function (TSF) is used for this purpose, only that it is performed for each cluster separately and the members synchronize with the clock of their cluster-head's beacon packet. The MTIM window follows the beacon window, in which the cluster-head informs its members about the broadcasting packet by sending an MTIM packet, thus they stay awake during the rest of beacon interval and receive the broadcasting packet.

The goal of the BTIM window differs from that of the MTIM window. In this window, the node is awake and listens to the media and no packet of any kind is sent. Here, the MTIM-ACK mechanism is not used for data transmission and non-quorum intervals are never used for sending and receiving unicast packets. The major goal of the BTIM window is to reduce energy consumption and is set to receive the BTIM packet from the broadcasting packet transmitter.

The cluster members use the synchronous IEEE 802.11 PSM mechanism for saving power and they need to be synchronous with their cluster-heads, thus the standard beacon interval IEEE 802.11 is used inside the clusters. To avoid more complexity of synchronization, we usually increase the number of clusters to have the nodes arranged in a single-hop structure inside the clusters, but there is not guarantee for it. It should be pointed out that considering synchronization mechanisms is not the aim of the present paper, and although the cluster members might be multi-hop, it is assumed that they are synchronous with their respective cluster-heads. Is_ChID and Is_MbreID fields are added to the beacon interval to determine cluster-heads and cluster members.

4.4. HBPS structure

HBPS analyzes every node that contains the broadcasting packet to find out whether it is a cluster-head or not. If the node is a cluster-head, other cluster-heads will be informed about the broadcasting packet through the BTIM packet. The BTIM packet is delivered only to the nodes known as cluster-heads by the LEACH protocol because cluster-heads are detectable from the node IDs. When all cluster-heads are informed about the broadcasting packet, the packet is sent to them through BQPS. In the next phase, the cluster-heads become synchronous with their members by sending the beacon packet. In the beacon interval, they send the MTIM packet to their respective cluster members and inform them of the broadcasting packet, therefore the member nodes remain awake in the beacon interval in order to deliver the broadcasting packet. Now, if the node which possesses the broadcasting packet is a member node of a cluster, it first sends the packet to its cluster-head by a unicast mechanism and then the process continues as explained before.

In mathematical terms if n is the number of nodes in the network that can be presented as $N= \{0, 1, ..., n-1\}$ and if c presents the number of clusters, the set of clusters would be $C= \{C_1, C_2, ..., C_c\}$. A cluster-head is determined for each cluster that can be presented as $CH= \{CH_1, CH_2, ..., CH_c\}$. The number of the members of C is equal to CH because one cluster-head is chosen for each cluster. CH is the subset of N ($CH \subset N$). Each member of C set, in addition to a cluster-head, has some nodes as its members (members that are chosen by the LEACH protocol). Sets of the cluster members can be presented as follows:

$C_1= \{k_0, k_1, ..., CH_1, ... ,k_{k-1}\}$ k: number of cluster members
$C_2= \{l_0, l_1, , ..., CH_2, ... ,l_{l-1}\}$ l: number of cluster members
....
$C_c= \{m_0, m_1, , ..., CH_c, ... ,m_{m-1}\}$ m: number of cluster members

where the number of different cluster members is not necessarily the same ($k \neq l \neq m$).

In the proposed mechanism for broadcasting packets, members of CH set use the asynchronous power saving mechanism based on the cyclic quorum system and employ the BQPS mechanism to send the broadcasting packet to each other. If a node possesses a broadcasting packet and wants to send it, first its ID is compared with the members of CH set and if it is one of the members, it is identified as a cluster-head. For example, if CH_1 wants to broadcast a packet, it needs to be in its quorum interval to be able to send the packet. The sender node retransmits n BTIM packets in the data quorum interval (n can be obtained from Eq. 6). These packets are delivered to all members of CH

set through the route requesting of the AODV routing protocol. The address of the members of *CH* is set as the destination address of the RREQ packets broadcasted in the network layer, and the nodes that have the same address as the destination address of the RREQ packets receive the BTIM packets and release the RREP packets. As soon as all members of *CH* set receive the BTIM packet, based on the packet's number and reception time, the transmission time of the broadcasting packet is estimated. This time that is known as waiting time is obtained from Eq. (8) below [10]:

$$W = \left[\left(\frac{Beacon\ Interval\ Size}{BTIM\ Window\ Size - txtime(BTIM)}\right) - n\right] \times (BTIM\ Window\ Size\ - txtime(BTIM)\ ) \qquad (8)$$

where *n* is the number of received BTIM packets. BQPS ensures that, apart from the number of nodes, one beacon interval is sufficient to inform all neighbours about the broadcasting packet. This way, in the next beacon interval when the waiting timer is expired, if members of *CH* set are in their quorum interval, they receive the broadcasting packet from the shortest and optimal discovered routes. But if they are in the non-quorum interval, they are activated in a transient interval and receive the packet through the discovered routes. What is interesting is that in multi-hop sensor networks any node receiving the broadcasting packet broadcasts it to the entire network, i.e., transmitting the broadcasting packet leads to its retransmission by the neighbours until all nodes of the network receive it. Therefore, as the number of nodes in the network increases, the power consumption for flooding a broadcasting packet increases. To inhibit collision other than the contention mechanism and back off which is used for sending packets in BQPS, when a node receives the BTIM packet, it does not transmit it until the time of waiting timer ends.

Now, among C_1, C_2, ..., C_c, only members of $CH=\{CH_1, CH_2, ... CH_c\}$ possess the broadcasting packet. In this step, all *CH*s are activated temporarily in their next beacon interval, either quorum or non-quorum, to deliver the broadcasting packet to their members. Members of *C* set are independently synchronous with their respective *CH*s' clocks, namely with the members of *CH*, i.e., members of C_1 with CH_1, C_2 with CH_2 and so on up to C_c with CH_c.

Suppose CH_2 has received the broadcasting packet and wants to transmit it to the members of C_2 cluster. First by sending the beacon packet in the beacon window, it synchronizes its time with the clock of the members of the cluster $C_2 = \{1_0, 1_1, , ..., CH_2, ..., 1_{1-1}\}$. Then it transmits a MTIM packet in the MTIM window to members of C_2 to inform them about the broadcasting packet. In return, members of C_2 send a join-request packet to CH_2 to ensure that they have been synchronized with its beacon packet's clock. This packet, called *kca*, is a small packet including the sender node ID (members of C_2 cluster) and the receiver node ID (CH_2) that is sent by the non-persistent CSMA protocol. This way, those members of C_2 that have received the MTIM packet and have sent the *kca* packet will remain active in the beacon interval and receive the broadcasting packet. The routing protocol used in this step is DSDV since the distances of the members of *CH* set from their corresponding members in *C* set are determined by the LEACH protocol and no mobility is set for the nodes of the network and the network's topology is fixed.

Cluster-Heads	List of cluster members						
CH_1	k_1	k_2	k_3	..	k_k		
CH_2	l_1	l_2	l_3	l_4	.		l_l
CH..	..	..	..	..	..	..	
CH_c	m_1	m_2	m_3	..	..	m_m	

Table 1
Cluster-heads and their members IDs

These procedures are repeated for all members of $CH=\{CH_1, CH_2... CH_c\}$, that possess broadcasting packets. In the proposed mechanism there is no need to synchronize the entire network since dense sensor networks are multi-hop, and local synchronization inside each cluster can solve the problem of synchronization in multi-hop networks.

If any node that has a broadcasting packet is not a member of *CH* set, it is not a cluster-head and needs to search for its ID in the member columns. When the node finds its ID in the member columns, it goes to the first column of that row to identify its corresponding *CH*. Then it transmits the broadcasting packet to its cluster-head in a unicast mechanism. Now one of the members of *CH* possesses the broadcasting packet and must transmit it to all members of *CH* set based on the procedure described above. Then it can be delivered to other members of the clusters in the next step. Table 1 shows the cluster-heads' IDs and their corresponding members.

In the proposed HBPS mechanism, the cluster-head possessing the broadcasting packet uses the AODV routing mechanism to transmit BTIM and the broadcasting packet to other members of *CH* set. As discussed before, cluster-heads use tables that include cluster-heads IDs to identify other cluster heads. It means that when a cluster-head wants to inform other cluster-heads about a broadcasting packet through the BTIM packet, it sets the table of cluster-heads' IDs in the address field of the AODV routing and then transmits the BTIM packets through the route requesting message (RREQ) in the network.

5. Evaluation

In this study, simulation of the mechanism suggested is done by the most important network simulator NS2. IEEE 802-11 standard protocol is installed on NS2 by default. Thus firstly it needs to add the power saving mode (PSM) and the cyclic quorum system to this standard, and then simulate the proposed mechanism. Stimulation for different number of nodes is done in a 1000 * 1000 area. The beacon interval and the initial power of each node are set to be 100 ms and 300 joule, respectively. The AODV routing protocol is used for sending packets to cluster-heads and the DSDV routing protocol is used for sending packets to members. Sizes of the broadcasting packet, quorum system, and BTIM window are 50 KB, 20, and 4.7 ms, respectively. Parameters used for evaluating the proposed mechanism include energy consumption, end to end delay of network, and network throughput. By taking different numbers of nodes such as 50, 100, 200, we

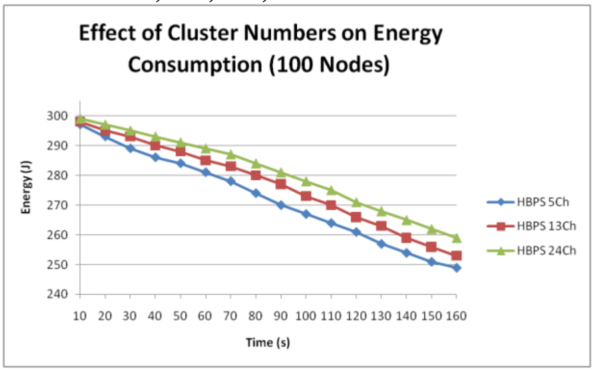

Fig. 6. Analysis of energy consumption for different numbers of cluster-heads (5-13-24) *in* 100 nodes

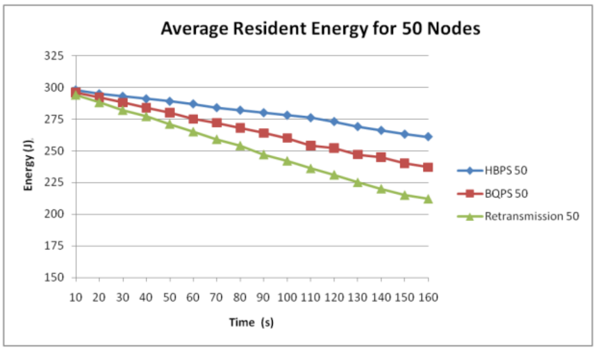

Fig. 8. Average remained energy for 50 nodes

can analyze the network in the high node density too. It is also possible to get the optimal number of clusters in which a network yields better results by changing the number of clusters. BQPS and retransmission mechanisms are taken to be compared with the proposed mechanism. The results indicate that the hybrid mechanism developed in this paper is more efficient than the existing mechanisms.

5.1. Optimal cluster number

To find the optimal number of clusters, different percentages (5-13-24) of the same number of nodes (100) are chosen as cluster-heads and then two parameters of energy consumption and end to end delay are calculated in the three modes and are taken for comparison. As shown in Figure 6, the consumption of energy in the mode in which the number of cluster-heads is 24% of the nodes is the lowest compared to the other modes. Yet according to Figure 7, when the cluster heads are 5% of the nodes, the end to end delay of the network is less than the other modes. So if we choose 13% of nodes as the number of clusters, the consumption of energy and end to end delay will be moderate.

5.2. Energy consumption

To analyze the network performance and individual effects of each mechanism on the network lifetime, the average remained energy of the nodes were measured in each 10

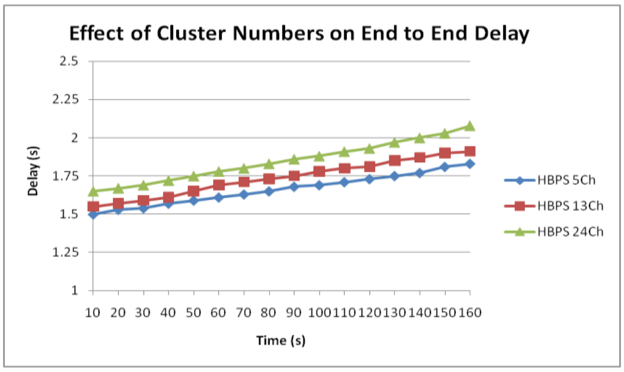

Fig. 7. Analysis of end-to-end delay for different numbers of cluster-heads (5-13-24) in 100 nodes

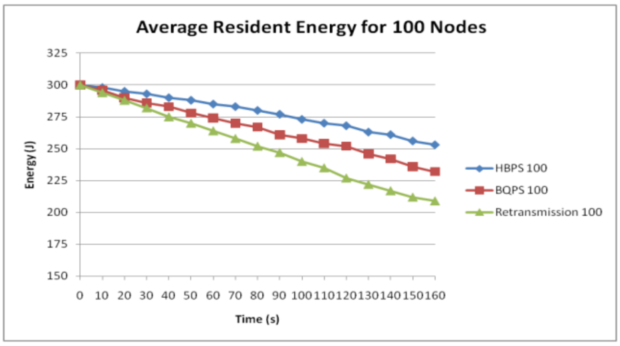

Fig. 9. Average remained energy for 100 nodes

seconds. Figures 8, 9 and 10 illustrate the average remained energy of nodes in which the networks have 50, 100, 200 nodes with the fixed quorum system size of 20, in which 13% of nodes are chosen as cluster-heads. Moreover, Figure 11 shows the amount of energy consumption. The applied traffic is a constant bit rate of 2 KB per second and is used similarly for all three mechanisms. The simulation results indicate that the proposed HBPS mechanism works well in saving energy.

5.3. Throughput and end to end delay

Throughput refers to the ratio of the number of application packets received by the receiver to the total number of application packets transmitted by the sender. Here, to have a more comprehensive approach, we have considered throughput in the entire network, i.e., if there are several senders and receivers in the network, the throughput is equal to the average throughput of each. Figure 12 demonstrates throughputs when the networks have 50, 100, 200 nodes. Different scenarios are used for this purpose. For example, in one scenario 4 nodes are used while in another scenario 7 nodes send packets to separate destinations with 2kB rate.

The average end to end delay of three mechanisms is presented in Figure 13. The parameter of end to end delay includes propagation delay, transmission delay and processing delay. Thus, results of the average delay of the broadcasting packet of the MAC layer, which is sent in the transport layer and is delivered to the application layer are calculated.

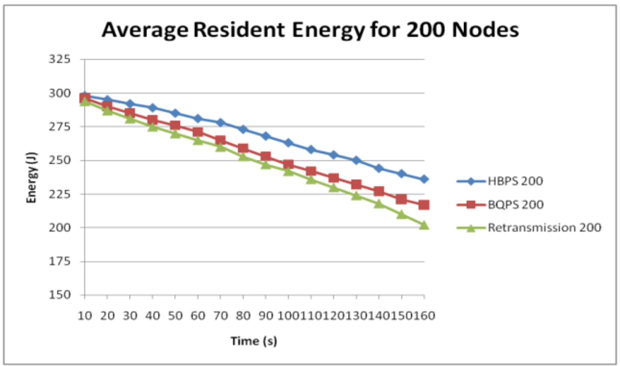

Fig. 10. Average remained energy for 200 nodes

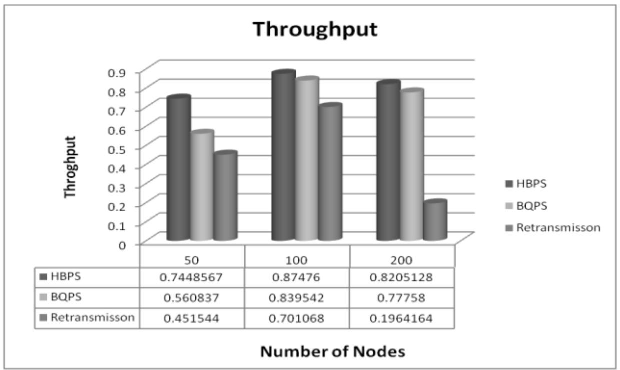

Fig. 12. Networks Throughputs

Since the packet is transmitted through two steps in the proposed mechanism, the delay of the packets that are transmitted to the application layer of the destination node is calculated. The findings reveal that increasing the number of nodes increases the delay of the two mechanisms investigated (BQPS and retransmission) more than that of HBPS.

6. Conclusion

The present paper proposes a hybrid mechanism with synchronous and asynchronous mechanisms to give a more efficient method for broadcasting in the asynchronous quorum-based systems. This cluster-based mechanism benefits from the advantages of both synchronous and asynchronous mechanisms simultaneously, i.e., by clustering the network and selecting a cluster-head for each cluster, it employs an asynchronous mechanism for communication between cluster-heads and a synchronous mechanism for communication between a cluster-head with its respective members. Results of the simulation demonstrate that the proposed mechanism outperformed the two mechanisms studied (i.e. BQPS and retransmission) with regard to the parameters of energy consumption and end-to-end delay. Besides, the ideal number of clusters in the network was 10-15% of all the nodes, and in dense networks, HBPS used less energy than other mechanisms. Finally, it was observed that some reduction in the end to end delay of the network improved throughput, particularly in the networks with a high node density.

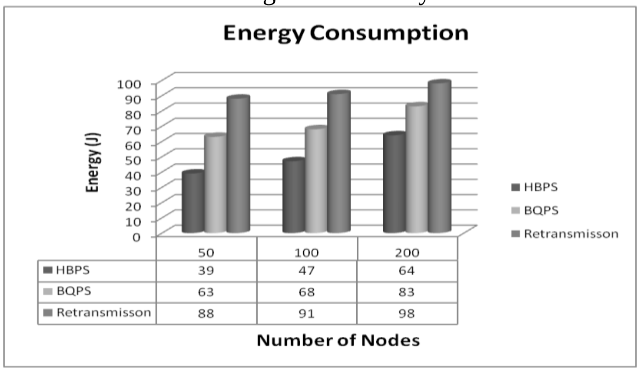

Fig. 11. Energy Consumption for different numbers of nodes (50-100-200)

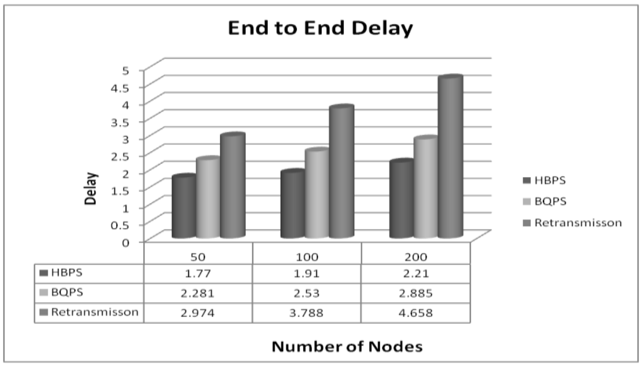

Fig. 13. Networks End to End Delay.

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