JOURNAL OF INFORMATION SCIENCE AND ENGINEERING 33, 1307-1322 (2017)
DOI: 10.6688/JISE.2017.33.5.12

An Asynchronous and Adaptive Quorum Based MAC Protocol for Wireless Sensor Networks

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The extension of the lifespan of sensor network is greatly reliable on sensor node's battery power. Scheduling and tuning sensor node's wake up and sleep duration plays an important role in minimizing the energy consumption. Hence, a new asynchronous, adaptive, heterogenous quorum based Medium Access Control protocol called Connected Dominating Tree Medium Access Control (CDT-MAC) is introduced, that tunes and dynamically adjusts the duty cycle of selected sensor nodes called dominators, based on the inter arrival time of the packets, and, assigns fixed duty cycle to the remaining sensor nodes in the network. These dominator nodes selection is accomplished during virtual backbone construction in which a subnet of Wireless Sensor Networks called Connected Dominating Tree (CDT) is created that consists of minimum number of dominators and connectors for aggregating and forwarding the data to the sink node. A new Quorum system called HiQuorum is also introduced that provides minimum quorum ratio and network sensibility and maximum rendezvous compared with existing dygrid system. Simulation results prove that CDT-MAC when applied with HiQuorum in CDT leads to high throughput and less delay, and thereby, improving the reliability and energy conservation of the sensor networks.

Keywords: wireless sensor networks, connected dominated tree, quorum, medium access control, rotation closure, virtual backbone

1. INTRODUCTION

Wireless Sensor Network (WSN) is a set of nodes that mainly senses, detects, aggregates and sends data to the sink node. The important aspects that mainly influence the sensor network performance are the capacity of the battery power, transmission scheduling and routing, broadcasting features of the network. Hence, the power aware MAC protocol design plays a vital role in the development of the WSN [1].

Various traditional Quorum systems like Grid, Tree, Torus, Extended Torus and Adaptive Quorum systems help in the design of MAC protocol [2, 3]. They are categorized into two namely, homogenous and heterogenous quorum systems. In homogenous quorum systems, all the sensor nodes follow the same duty cycle, while in heterogenous quorum systems all the sensor nodes follow different duty cycle. Also, clock synchronization is not needed in asynchronous wake up scheduling [4]. The nodes will follow their

Received October 14, 2014; revised November 7, 2016; accepted December 28, 2016.
Communicated by Ruay-Shiung Chang.

own sleep and wake up schedule based on factors like traffic load, power consumption *etc.* to transmit the data [5-8]. Thus the overlapping of the wake up time intervals of different sensor nodes becomes a challenge in the design of the MAC protocol [9]. Hence, a new quorum system named HiQuorum is introduced which guarantees the overlapping of wake up time intervals.

Relay nodes are highly in demand for data communication in WSN due to the sensor node's narrow transmission range. Connected Dominating Set (CDS) is considered as the virtual backbone in the networks which achieves energy efficient routing in the sensor networks [10]. The nodes that are in the CDS will only forward data to the other nodes. A wireless network is represented as a graph $G(V, E)$, where all the vertices are denoted by V and all the edges are denoted by E. A subset K of V is said to be a Dominating Set (DS), if all nodes in V of G are available either in the subset K or is neighbor to minimum of one node in K. A CDS named C of G is said to be a connected sub graph of G as well as a dominating set. Therefore, all the nodes in the graph G can communicate to at least one node in C with one hop distance. When the size of the CDS is minimized to the maximum, then it is said to be Minimum Connected Dominating Set. But, when the size of CDS becomes too small, it leads to the elimination of some important features of the original network.

The proposed work focuses on the construction of new CDS with minimum size, while the length of the routing path does not increase much through the CDS nodes. In this paper, a CDS named CDT is constructed that includes minimum number of dominator and connector nodes to transfer the data to the sink node [11]. A new homogenous and adaptive quorum system called HiQuorum is introduced that provides low quorum ratio and network sensibility and high rendezvous points compared to that of the existing dygrid and BiQuorum systems [12]. A newly introduced MAC protocol named CDT-MAC, when applied with HiQuorum, dynamically changes the sensor node's sleep and wake up time based on the inter arrival time of the packets.

This paper is organized as follows: Research associated to this topic is discussed in Section 2. The assumptions are explained in Section 3. The construction of CDT is given in Section 4. The scheduling of wake up pattern is given in Section 5. The performance analysis is discussed in Section 6. Section 7 discusses about the outcomes of the simulation and the conclusion is specified in Section 8.

2. RELATED WORK

W. Ye *et al.* [13] have proposed a protocol named *S*-MAC protocol that follows periodic sleep and listen scheduling which greatly decreases the energy depletion due to idle listening. Here, sleep and wake up time periods are predefined and not suitable for the network under varying traffic load thereby leading to idle listening problem. To overcome the drawbacks of *S*-MAC protocol, T. V. Dam and K. Langendoen [14] developed a protocol named *T*-MAC. Here, the nodes will be made to be in the wake up state for a threshold period of T_A. If no activation occurs in the threshold period, the nodes will enter into the sleep state. But this protocol suffers from early sleeping problem.

C. M. Chao and Y. W. Lee [15] defined QMAC which is a non-adaptive, asynchronous, homogenous protocol. This protocol makes use of grid quorum system which follows its own schedule of sleep and wake up. A protocol named QueenMAC with dy-grid quorum system is used to regulate and dynamically schedule the sleep and wake up time of the sensor nodes based on their traffic loads [16, 17]. This protocol is vulnerable to collision since there is no flexible method for assignment of channels for data transmission. In DMAC protocol, the data transmission is done based on the wake up time slots provided by the data gathering tree. This protocol suffers from collision, if the children of a particular node try to transmit the data simultaneously [18].

H. Du *et al.* [19] have proposed a connected dominating set called GOC-MCDS-C which consists of two phases. An MIS is constructed during the first phase, and during the second phase, all pair shortest path algorithm is used to construct the CDS. Though the algorithm produces minimum CDS, the running time and routing cost is high and this causes high delay in transmission. R. Yu *et al.* [20] developed an algorithm that consists of two phases to construct a connected dominated tree. The nodes with smallest id are identified as dominators to form the forest of nodes, and later linked using the connectors to form the CDS. This algorithm leads to the extension of the network reliability but the constructed CDS are not minimal, and hence leads to high power consumption.

L. Ding *et al.* [21] defined a technique called MOC-CDS which is an efficient technique and provides minimum cost preserving routing. In order to achieve better transmission, the wake up time intervals of the sender node are organized in such a way that they overlap with at least one wake up time interval of the receiver node during each duty cycle.

3. PRELIMINARIES

3.1 Assumptions

The following are the assumptions made in the proposed algorithm. All the sensor nodes are static and follow the same transmission range. The proposed architecture includes two phases, namely, construction of the Connected Dominating Tree, scheduling of wake up pattern using CDT-MAC protocol and data forwarding.

The first phase is to construct a virtual backbone with minimum CDS which proceeds with a tree like structure called CDT for the transmission of data. The second phase of the architecture includes the scheduling of the wake up patterns of the sensor nodes. An energy efficient MAC protocol called CDT-MAC is developed, to allow the sensor nodes to go into wake up and sleep states dynamically based on the inter arrival time of the packets. This phase also includes data forwarding in which, all the nodes in the CDT help in communicating data to sink node.

4. CONSTRUCTION OF CDT

The construction of the minimum CDS is used to generate the virtual backbone in Wireless Sensor Network. A connected subgraph of graph $G(V, E)$ which is also a DS forms CDS C of G. An Independent Set (IS) is said to be a subset X of graph G if for any two vertices of X; there lies no edge between them. A Maximal Independent Set (MIS) is said to be an IS and also a DS which occurs when there is a violation due to the addition of new node to IS. The construction of the CDT has two phases, in which the first phase called MIS creation identifies dominators. The second phase called connectors' creation connects the MIS or dominators with the sink.

4.1 Maximal Independent Set Creation

Algorithm 1 identifies the MIS or dominators which processes and forwards the data from the dominatees or cluster members.

Algorithm 1: CreateMIS

Input: Graph ($G(V, E)$)
1: Initially identify the sink node S and every node is colored white.
2: All the one hop neighbors of node S is colored grey.
3: Do the following until all the nodes are colored grey or black
    3.1 Among the neighbors of each grey node
        Do the following
        a: Identify the node with highest residual energy
        b: Turn the color of the node from white to black
        c: For each black node
            Do the following
            i. Color the one hop neighbors of black node from white to grey

Output: All the black nodes form the MIS, all the grey nodes form the dominatees.

4.2 Connectors Creation

This phase identifies the connectors in the network. Among the one hop neighbors of the sink, nodes that connect maximum number of dominators are identified and become connectors. The CDT includes the sink node which takes the first level in the CDT, followed by the connectors, dominators and dominatees in the second, third and fourth level respectively. Algorithm 2 identifies the relay nodes or connectors to connect the dominators to the sink node for the data transmission from dominatee.

Algorithm 2: CreateConnectors

Input: Graph ($G(V, E)$)
1: Among the entire one hop neighbors of the sink node
    a. Find a node that has maximum black nodes as its one hop neighbor.
    b. Turn the color of the node from grey to red.

Output: All the red nodes form connectors and all the black and red nodes form CDT.

5. SCHEDULING OF WAKE UP PATTERN

The sleep and wake up pattern will be chosen by each sensor node after CDT is constructed. The proposed CDT-MAC protocol helps in choosing the sleep and wake up patterns, and satisfies the following constraints of the WSN: Firstly, the wake up time intervals of the sensor nodes should intersect with each other in every cycle length. Secondly, even if there is clock drift, the wake up time intervals of the sensor nodes must overlap with each other. Thirdly, the duty cycle of the sensor nodes is dynamically adjusted. The beacon time intervals are divided into two categories, namely, Quorum (wake up time intervals of the sensor nodes) and Non Quorum (sleep time intervals of the sensor nodes).

5.1 HiQuorum

A Quorum system is said to be a superset of non-empty subsets of elements where each subset is a quorum that achieves intersection property. The new proposed quorum called HiQuorum provides both low and adaptive quorum ratio, which outperforms the existing quorum systems.

Definition 5.1 First-Select (*Y*): Given a universal set of $Z = \{0, 1, \ldots, n-1\}$ where n is a positive integer. Let Y be an integer whose value equals 1. A First-Select (1) denoted as $FS(1)$ is defined by the Eq. (1).

$$FS(1) = \{(0, \sqrt{n}, 2\sqrt{n}, \ldots, (\sqrt{n}-1)\sqrt{n})(\bmod n)\} \tag{1}$$

For example, in Fig. 1, when $n = 16$, and if n is shown as $\sqrt{n} \times \sqrt{n}$ grid, $FS(1) = \{0, 4, 8, 12\}$.

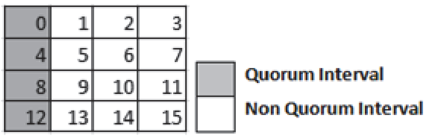


Fig. 1. First-Select(1).

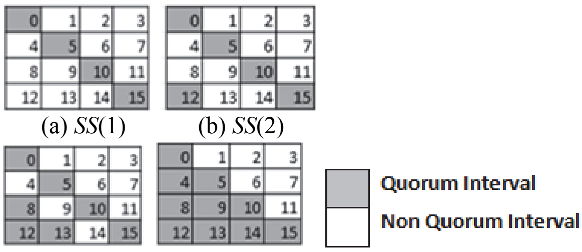
Definition 5.2 Second-Select (*X*): Given a universal set of $Z = \{0, 1, \ldots, n-1\}$ where n is a positive integer. Let X be an integer where $1 \le X \le \sqrt{n}$. A Second-Select(X) denoted as $SS(X)$ is defined by the following Eq. (2).

$$SS(X) = \{((j-1)(1+\sqrt{n}))(\bmod n)\} \tag{2}$$

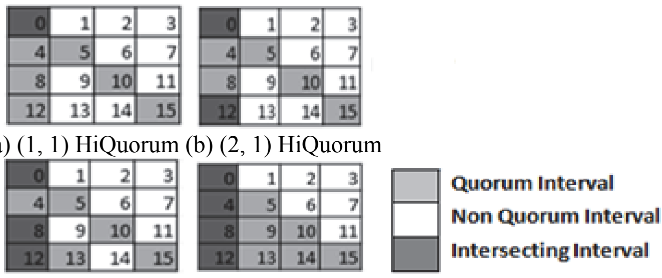
$$\text{where } i = \begin{cases} 1, & X = 1 \\ 1, \sqrt{n}, & X = 2 \\ 1, \sqrt{n}, \sqrt{n}-1, \ldots, \sqrt{n}-(X-2), & X \ge 3 \ldots \sqrt{n} \end{cases} \quad \text{and}$$

$$j = (((i-1)\sqrt{n})+1), \ldots, ((i\sqrt{n})-(i-1)).$$

The $SS(1)$, $SS(2)$, $SS(3)$ and $SS(4)$ are shown in Figs. 2 (a)-(d) respectively.



(a) *SS*(1) (b) *SS*(2)
(c) *SS*(3) (d) *SS*(4)
Fig. 2. Second-Select*(X*).



(a) (1, 1) HiQuorum (b) (2, 1) HiQuorum
(c) (3, 1) HiQuorum (d) (4, 1)HiQuorum
Fig. 3. (*X*, 1) HiQuorum.

Definition 5.3 (*X*, 1) HiQuorum: Given an integer X, $1 \leq X \leq \sqrt{n}$, let A and B be the sets of the non-empty subsets of Z, where $Z = \{0, 1, \ldots, n-1\}$. The pair ($A$, B) is said to be (X, 1) HiQuorum if and only if A is a *SS*(X) and B is a *FS*(1) or B is a *SS*(X) and A is a *FS*(1). This is denoted as (X, 1) HiQuorum. For example, for $n = 16$, (1, 1) HiQuorum, (2, 1) HiQuorum, (3, 1) HiQuorum, (4, 1) HiQuorum is shown in Figs. 3 (a)-(d) respectively.

The main advantage of HiQuorum System is that, the size of the *SS*s is minimum, compared to that of the BiQuorum, dygrid and grid system. The HiQuorum system clearly indicates and guarantees the intersection between *FS* and *SS*. Fig. 4 illustrates that the total number of intersections will range from 1 to $\sqrt{n}$ based on the value of X. The $(\sqrt{n},1)$ HiQuorum has $\sqrt{n}$ intersections which is higher than that of dygrid and grid quorum systems.

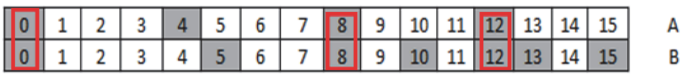


Fig. 4. Overlapping of sensor node's wake up time intervals {0, 8, 12} in (3, 1) HiQuorum.

5.2 Asynchronous Protocol

In asynchronous wakeup scheduling, there is no need for time synchronization. Since the proposed protocol satisfies the rotation closure property, it is proved that the overlapping of time slots is guaranteed, even if there is a clock drift.

Theorem 1: The HiQuorum system fulfills the rotation closure property.

Proof: For any given positive integer 'i' and a quorum Y in a quorum system Q under $Z = \{0, \ldots, n-1\}$, Rotation Closure is denoted by $(RC(Y, i)) = \{(i+j) \bmod n \mid j \in Y\}$. A quorum Q under $Z = \{0, \ldots, n-1\}$, is said to satisfy rotation closure property $\forall X, Y \in Q$, $i \in \{0, \ldots, n-1\}$: $X \cap RC(Y, i) \neq \{\varnothing\}$. Let Q be the HiQuorum made by $\sqrt{n} \times \sqrt{n}$. Sensor node A takes the lower left diagonal elements as its quorum intervals, depending on the value of X. Let $A \in Q$ which contains the left diagonal elements of the grid, namely, $\{(0, \sqrt{n}+1, 2\sqrt{n}+2, \ldots, n-1)(\bmod n)\}$. It follows that $A \cap RC(B, i) \neq \{\varnothing\}$ where $B \in FS(1)$. Hence it is proved that the sensor nodes can tolerate time slot drifting, thereby fulfilling the rotation closure property.

Theorem 2: Any hosts A and B that runs the HiQuorum system have the intersections of maximum of, drifted time slots of A and B, in every 'n' cycle intervals. For any integers a, b, $RC(A, a) \cap RC(B, b) \leq \max(a, b)$ where $A \in SS(X)$, $B \in FS(1)$ and $X = \{1, \ldots, \sqrt{n}\}$.

Proof: The maximum number of intersections of $RC(A, a) \cap B$ is less than or equal to 'a', for $X = \{1, \ldots, \sqrt{n}\}$. Therefore, the total number of intersections is given in Eq. (3).

$$RC(A, a) \cap B \leq a \tag{3}$$

The maximum number of intersections of $A \cap RC(B, b)$ is less than or equal to b, for $X = \{1, \ldots, \sqrt{n}\}$. Therefore, the total number of intersections is given in the Eq. (4).

$$A \cap RC(B, b) \leq b \tag{4}$$

Thus by Eqs. (3) and (4) the Eq. (5) is obtained.

$$RC(A, a) \cap RC(B, b) \leq \max(a, b) \tag{5}$$

Therefore, it is clear that any two neighbor sensor nodes A and B that adopt (X, 1) HiQuorum will meet each other within a maximum clock drift time slots of nodes A and B in every 'n' cycle intervals.

14	15	0	1	2	3	4	5	6	7	8	9	10	11	12	13	B
13	14	15	0	1	2	3	4	5	6	7	8	9	10	11	12	A

Fig. 5. After 2 time slot drifts in node B and 3 time slot drifts in node A.

Fig. 5 shows the overlapping of the time intervals in spite of 2 time slot drifts in node B along with 3 time slot drifts in node A. The HiQuorum system fulfills rotation closure property since $RC(A, 3) \cap RC(B, 2) \leq \max(2, 3)$. Thus there are three intersections {14&13, 6&5, 10&9} in (3, 1) HiQuorum with node B follows $SS(3)$ and node A follows $FS(1)$ which is still a non-empty set. Therefore, even if, the sensor nodes follow asynchronous duty cycling and have clock drifting, the nodes wake up simultaneously.

5.3 CDT-MAC Protocol Description

To achieve power conservation, CDT-MAC protocol identifies the wake up frequency of the sensor nodes based on the Packets Inter Arrival Time (PIAT). This protocol has an advantage that, except dominators, the remaining nodes need not adjust their wake up time intervals. Algorithm 3 describes the selection of wake up schedule for sensor nodes.

Algorithm 3: Wake up Schedule based on PIAT

Input: $G(V, E)$, PIAT, i: sink node

```
for all V∈G(V, E)
if (V==i) then wake up = SS(4)
else if ((V∈dominatee || connector) then wake up = FS(1)
end if
end if
while ((V∈dominator)
          if (PIAT ≤ 2.56 ) then wake up = SS(4)
               else if (2.56 < PIAT ≤ 3.70 ) then wake up = SS(3)
                    else if (3.70 < PIAT ≤ 5.26) then wake up = SS(2)
                         else if (5.26 < PIAT ≤ 6.25) then wake up = SS(1)
                         end if
                    end if
               end if
          end if
  end while
end for
```

Output: Wake up schedule for sensor nodes

As the sink node is heavily loaded with data, the wake up schedule for the sink node is assigned with maximum wake up time intervals *i.e.* $SS(4)$. Since the dominatees have less participation in data transmission, they are assigned with minimum wake up time intervals *i.e.* $FS(1)$. As the dominatees are given $FS(1)$, the connectors or red colored nodes are also given $FS(1)$ to get intersect with the dominators. Finally, the dominators will be assigned with different wake up pattern dynamically based on PIAT. Assume that a time interval is 0.1s long and the grid size is 4×4. From Fig. 2 (d), it is understood that the total wake up time intervals for $SS(4)$ in the grid are 10 *i.e.* (0, 4, 5, 8, 9, 10, 12, 13, 14, 15). Therefore, the ratio of wake up time intervals of the dominator is 0.63 *i.e.* it can handle maximum of 6.3 units of traffic/s. This indicates that the traffic load for dominator is 6.3/16 ≈ 0.39 units of traffic/s^2 which is corresponding to a unit of traffic being generated every 2.56s. Therefore, the tolerable traffic arrival time is 2.56 sec and 3.70 sec for $SS(4)$ and $SS(3)$ respectively. The rest may be deduced by analogy.

Fig. 6 explains the working principle of the CDT-MAC protocol. Based on PIAT, the dominator is assigned with $SS(3)$, there will be three intersecting time intervals with the dominatee and connector *i.e.*, 0, 8 and 12. Therefore the dominators determines the number of intersecting wake up time intervals with the dominatees and the connectors, hence they can either increase or decrease the transmission based on PIAT and thereby increasing the throughput.

Dominatee FS(1)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Dominator SS(3)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Connector FS(1)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sink SS(4)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Fig. 6. Wake up schedule of the dominator.

6. PERFORMANCE ANALYSIS

The most important metrics that are measured in the following experimental study with regard to the HiQuorum are the Quorum Ratio, Network Sensibility and Rendezvous. The proposed system provides the maximum adaptiveness, minimum duty cycle and minimum network sensibility when compared with the dygrid systems.

6.1 Quorum Ratio

The ratio of total number of wake up time intervals in each cycle is defined to be Quorum Ratio. The major advantage of the HiQuorum is that the quorum ratio is minimum compared to dygrid systems. For example, for a 4×4 grid with ((2, 1)HiQuorum) takes 5 wake up slots out of 16 slots whereas for the same grid size, the dygrid (3, 6, 2, 1) takes 8 wake up slots out of 16. Due to its low duty cycle, HiQuorum when applied in wireless sensor network leads to reduced energy consumption. As the size of cycle length gets increased, the quorum ratio gets decreased.

6.2 Network Sensibility

Network Sensibility (NS) is defined to be the maximum delay by a sensor node to find its neighbor node. It is the maximum space between two farthest mutual elements in the quorum system. Given a positive integer $X \le \sqrt{n}$, the network sensibility of (X, 1) Hi-Quorum is identified and defined in Eq. (6).

$$NS = \begin{cases} 2\sqrt{n}, & 1 \le X \le \sqrt{n} - 1 \\ 2\sqrt{n} - 1, & X = \sqrt{n} \end{cases} \tag{6}$$

The comparison between the network sensibilities of the HiQuorum and dygrid quorum systems are shown in Fig. 7. It proves that the network sensibility of the HiQuorum is less than that of the dygrid system. It obviously shows that the HiQuorum system takes less time to detect their neighbor nodes. Thus it is understood that, smaller the cycle length, the minimum the network sensibility, and higher the quorum ratio.

6.3 Rendezvous

It is the total number of intersecting time intervals of any two sensor nodes. For example in a 4×4 grid, in order to provide two rendezvous points, the node will be wake up for $2\sqrt{n} + \sqrt{n}$ duty cycles together for sender and receiver nodes in the dygrid system. In the HiQuorum system, to obtain the same rendezvous points both the nodes need to be wake up for $\sqrt{n} + 5$ time intervals.

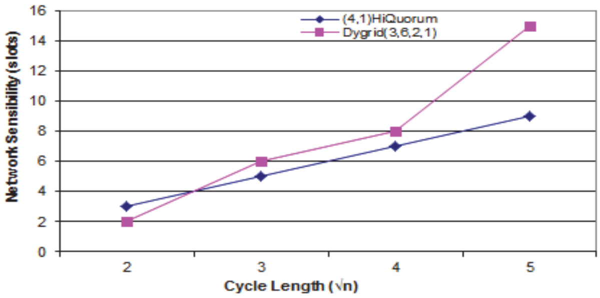


Fig. 7. Network sensibility in different cycle lengths.

7. SIMULATION RESULTS

NS2 Simulator is used to measure the performance of CDT-MAC protocol. Table 2 presents the various simulation parameters used in the implementation. The CDT-MAC protocol is compared with the existing QueenMAC protocol. A 512-byte data packet is produced by each node for every second. The metrics that measure the efficiency of the CDT-MAC are energy consumption, delivery ratio, and end-to-end delay.

Table 2. Simulation parameters.

Simulation Parameters	Value
Simulation Time	50 sec
Traffic Source	CBR
Packet Size	512 bytes
Transmit Power	0.660 W
Receiving Power	0.395 W
Idle Power	0.035 W
Initial Energy	10.1 J
Routing Protocol	AODV
Cycle Length	16
MAC	CDT-MAC, QueenMAC

7.1 Energy Consumption

The network reliability decreases as the energy consumption increases. The protocol CDT-MAC shows extensive decrease in energy consumption when compared with QueenMAC under varying number of flows, nodes and different arrival rates in Figs. 8-10 respectively. Though the duty cycle of the sensor nodes in QueenMAC get dynamically changed, the usage of multiple channels to transmit the data, increases the packet overhead and leads to energy consumption. In CDT-MAC, the duty cycle of the dominators alone gets dynamically adjusted under varying packet's inter arrival time thus leading to high energy conservation. Together with the benefits of the HiQuorum's minimum quorum ratio and maximum rendezvous, the CDT-MAC greatly reduces the energy depletion.

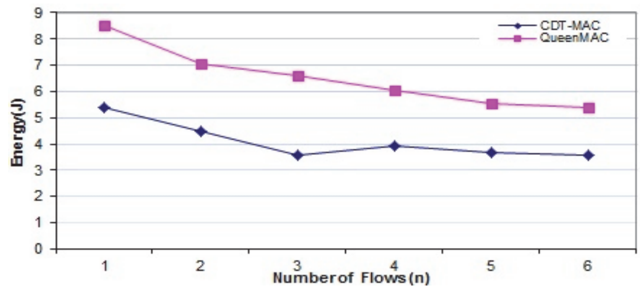


Fig. 8. Energy consumption under varying flows.

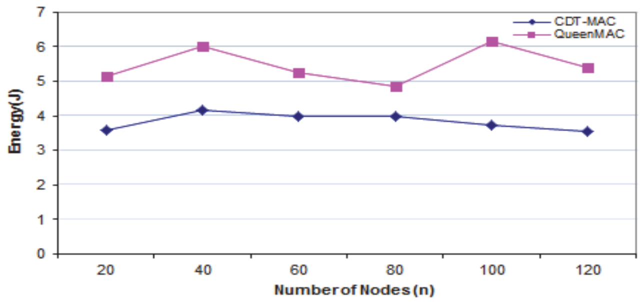


Fig. 9. Energy consumption under different number of nodes.

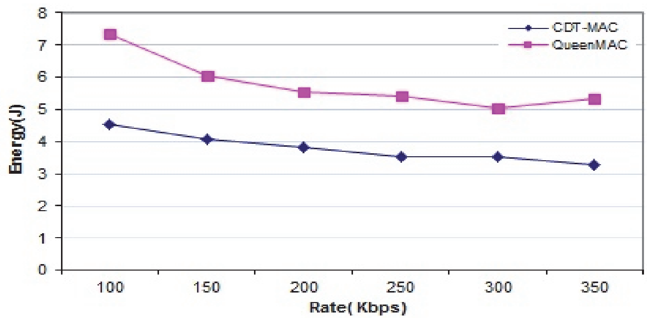


Fig. 10. Energy consumption under varying arrival rates.

7.2 End-to-End Delay

The transmission delay for the packets to the sink node is termed as End-to-End delay. Figs. 11-13 show that the delay of the CDT-MAC is lower than that of the existing QueenMAC protocol under varying flows, number of nodes and different arrival rates. In QueenMAC, the increase in forwarder nodes increases the collisions and retransmissions of data, thus leading to high transmission latency. In CDT-MAC, the increase in rendezvous points and decrease in network sensibility by HiQuorum increases the data transmission, thereby decreasing the transmission delay.

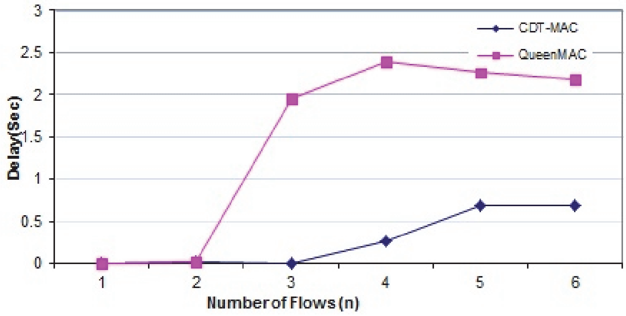


Fig. 11. End-to-End Delay under varying flows.

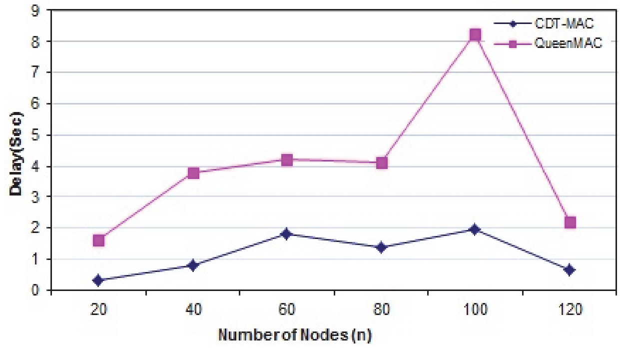


Fig. 12. End-to-End Delay under different number of nodes.

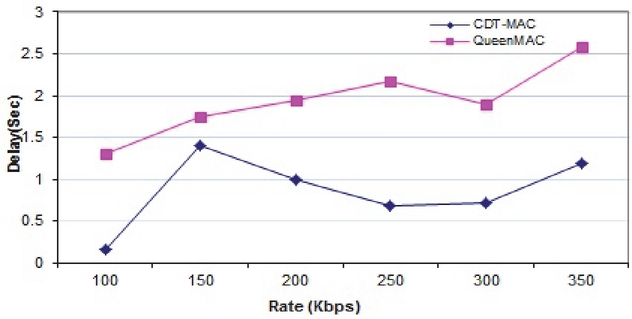


Fig. 13. End-to-End Delay under varying arrival rates.

7.3 Packet Delivery Ratio

Packet Delivery Ratio is defined as the ratio of the packets received by the receiver to the packets sent by the sender. Though QueenMAC has multiple channels for data transmission, the non-adaptive nature of the protocol leads to high energy consumption which further leads to a poor delivery ratio. In the CDT-MAC, since the dominators dynamically adjust the duty cycle efficiently, the delivery ratio is increased. Also the high intersecting quorum intervals falling within the low duty cycle results in high delivery ratio. From Figs. 14-16 it is clear that the HQMAC has a significant maximum delivery ratio compared to that of QueenMAC.

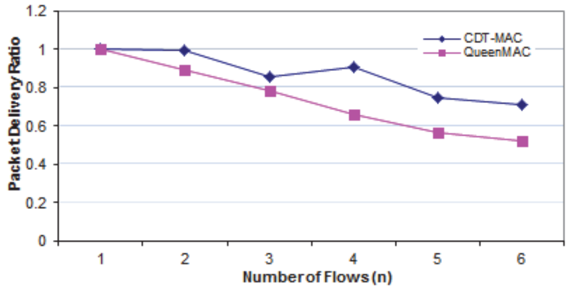


Fig. 14. Packet Delivery Ratio under varying flows.

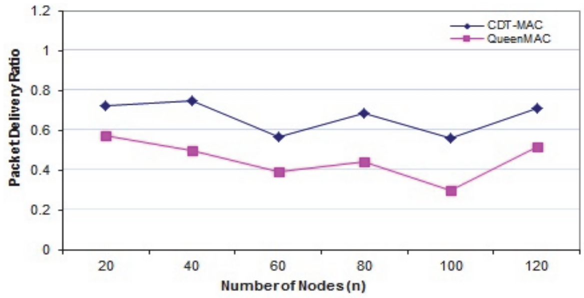


Fig. 15. Packet Delivery Ratio under different number of nodes.

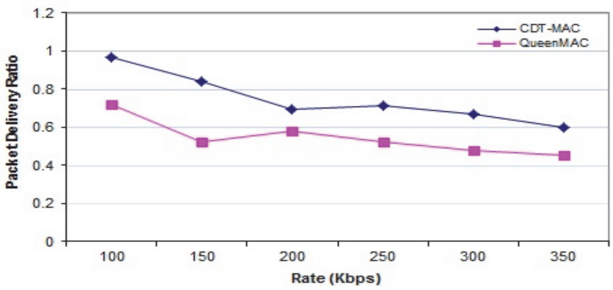


Fig. 16. Packet Delivery Ratio under varying arrival rates.

8. CONCLUSION

A new homogenous quorum system called the HiQuorum system is evaluated and it guarantees the overlapping of the wake up time intervals for the sensor nodes to transmit the data. The theoretical results also prove that the HiQuorum decreases the duty cycle and the rendezvous points, and increases the network sensibility, when compared with existing dygrid system. A new asynchronous MAC protocol CDT-MAC is introduced which helps in tuning and scheduling the wake up time intervals depending on PIAT. For effective routing, a virtual backbone is constructed using a CDT which consists of minimum number of the dominators, and connectors for the transmission of data, from the dominatee to the sink. The CDT-MAC protocol along with HiQuorum applied on to the CDT, successfully regulates and identifies the total wake up time intervals in each duty cycle for all the sensor nodes except the dominators. The energy consumption of the CDT-MAC is significantly reduced by permitting only the dominator nodes to dynamically tune its duty cycle depending upon PIAT. Both the theoretical and the simulation results proved that the CDT-MAC provides a low latency, energy consumption and high delivery ratio, compared to QueenMAC protocol.

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