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IMPROVING THE LIFESPAN OF WIRELESS SENSOR NETWORKS VIA EFFICIENT CARRIER SENSING SCHEME-CSMA/SDF

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ABSTRACT

Wireless Sensor Networks (WSNs) refers to a group of spatially dispersed and dedicated sensors for monitoring and recording the physical conditions of the environment like temperature, sound, pollution levels, humidity, etc. WSNs are deployed where manual intervention and wired infrastructure installation is not feasible. Lifetime of WSNs is of major issue. Energy efficient WSNs are to be deployed to improve the network lifespan instead of replacing nodes frequently which is of high cost. In this paper, we propose CSMA/Shortest Data First (SDF) an energy efficient MAC protocol, to increase the network lifetime. CSMA/SDF modifies existing CSMA/CA protocol which is completely contention-based, by introducing a higher priority to the node with shortest data during channel access contention process. CSMA/SDF employs a distributed shortest-data-first scheduling algorithm and Anti-Starvation mechanism to allow nodes with long data also given chance to get channel access. CSMA/SDF thus reduces overall energy consumption which in turn increases network life. It also efficiently utilizes channel by reducing the probability of occurrence of collisions. The proposed solution is simulated using a discrete event network simulator, ns2.35 on UBUNTU 12.04 LTS 64 bit Operating System. The simulated results of CSMA/SDF outperforms CSMA/CA by reducing carrier sense time by 42% and overall energy cost by 24% and improving channel utilization up to 46% and throughput by 36%.

KEYWORDS: Wireless Sensor Networks; Medium access control; CSMA/CA; CSMA/SDF; Network lifetime; sensor nodes.

INTRODUCTION

Wireless Sensor Networks (WSNs) refers to a group of spatially dispersed and dedicated sensors for monitoring and recording the physical conditions of the environment like temperature, sound, pollution levels, humidity, etc. WSNs consists of large number of source nodes and few number of sink nodes.Energy efficiency is the major challenge in wireless sensor networks (WSNs) as they have limited battery power. As the burden on nodes nearer the sink is more, the energy of these nodes deplete very fast. Medium access control (MAC) in wireless sensor networks (WSNs) is responsible for channel access policies, scheduling, and error control and buffer management. The major sources of energy consumption in MAC are collision, overhearing, and idle listening. Hence, the lifetime of WSNs, depends on the energy consumed during sink node communication and carrier sensing. The communication in Wireless Sensor Networks has many-to-one property. So, the nodes that are nearer to the sink will have heavier workload. Generally, a typical WSN contains many sensor nodes and one or more sinks. The sensor nodes are used to sense and collect information from environment. The data collected from all nodes are transmitted to a few receivers (i.e. sinks) using multi hop routing. The sensor nodes that are around the sink will need to relay data that collected from nodes which are far away from the sink. Thus, the sensor nodes near the sink will have faster power depletion than the distant nodes. This phenomenon is called “energy hole problem” or “crowded centre effect”. When deploying large-scale WSNs, the energy cost of carrier sense during nodes-sink communication cannot be negligible. The carrier sense in nodes-sink communication is one of the key energy costs, which may equal to energy cost of receiving or transmitting.

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From the above discussion, it is clear that most of energy is wasted in sensing the carrier. There is a need to employ a method to reduce the energy consumption.

In this paper, we propose CSMA/Shortest Data First (SDF) an energy efficient MAC protocol, to improve the network lifespan. CSMA/SDF modifies existing CSMA/CA protocol which is completely contention-based, by introducing a higher priority to the node with shortest data during channel access contention process. CSMA/SDF employs a distributed shortest-data-first scheduling algorithm and Anti-Starvation mechanism to allow nodes with long data also given chance to get channel access.

RELATED WORK

The role of medium access control (MAC) layer is it controls when and how each node can transmit in the wireless channel. As Wireless channel is a shared medium, radios transmitting in the same frequency band interfere with each other called collisions.In wired links, Carrier Sense Multiple Access with Collision Detection (CSMA/CD) is used for channel allocation. Data is sent, only when the medium is free. If the medium is busy, occurrence of collision is detected and the node waits until the medium is free.

In wireless links, signal strength decreases in proportional to at least square of the distance .Also collision detection is possible only at receiver. Carrier sensing is not possible beyond the transmission range. So, Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is used in wireless links.

A. Primary Concerns of MAC:

1. Collision avoidance: It is the basic task of a MAC protocol. Mac layer determines when and how to access the medium.
2. Energy efficiency: It is one of the most important challenges for sensor networks, as most nodes have limited battery source which affect the overall node lifetime. So, energy efficient MAC protocols are to be developed that increase network lifetime which reduces cost of frequent node deployment.
3. Scalable and adaptable: Nodes deployed will form an ad-hoc network that operates in uncertain environments. Nodes may die, join later and move from one place to other. As a result, network size and topology changes frequently. A good MAC is adaptable to changes.
4. Throughput: The amount of data transferred from sender to receiver in unit time is called Throughput. It is affected by efficiency of collision avoidance, channel utilization, control overhead and latency.
5. Fairness: Fairness is concerned with whether all the nodes share the channel equally or not. All nodes in a WSN cooperate for a single common task. Fairness has less importance in sensor networks
6. Latency: Time taken for the transmission of data or control packets from sender to receiver is called Latency. Latency should be minimum.

B. Energy consuming sources in MAC:

1. Collisions: When collisions occur, data is lost. So, data is retransmitted, which consumes more power. Thus collisions are to be avoided to conserve more power.
2. Long idle time:
    - Burst traffic in sensor network applications.
    - Idle listening consumes 50—100% of the power for receiving
3. Overhearing unnecessary traffic: As data is transmitted in broadcast manner, nodes other than destined nodes may also hear the data over radio. This is called overhearing. It can be a dominant factor of energy waste when there is
    - Heavy traffic load
    - High node density
4. Control packet overhead: As overhead increases, computation complexity increases and effects overall throughput.

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C. Classification of MAC protocols

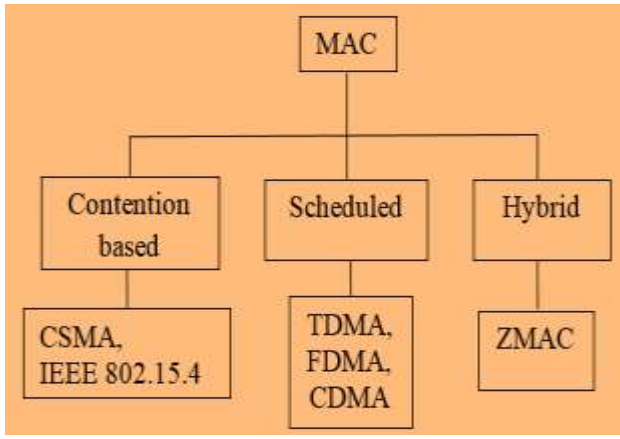

Fig. 2 Classification of MAC protocols.

The MAC protocols are mainly classified into three types. Figure 1 depicts the classification of MAC protocols. Thaskani *et al.* [1] divided the entire time into three slots as Communication Request (CR) slot, Channel Allocation (CA) slot and Data Section (DS) slot. They have improved channel utilization capability.Hongwei Tang *et al.* [2] classified the energy efficient CSMA based MAC protocols as shown in figure 2.

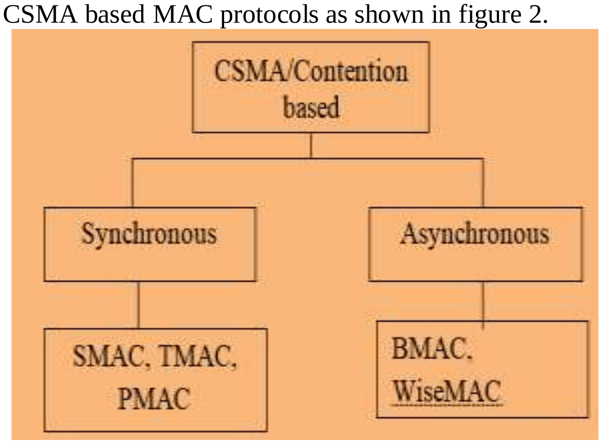

Fig. 2 Classification of energy efficient CSMA based MAC protocols

Ao Zheng *et al.* [3] proposed a new Pattern-MAC (PMAC) Protocol in which the sleep and wake up schedules of the sensor nodes are determined adaptively. The node's own traffic and its neighbours decides the schedules. Xiaoyu Li *et al.* [4] proposed that priority can also be employed while transmitting data which can reduce transmission delay and decrease energy consumption of network. Pande *et al.* [5] have showed the advantages of low power consumption and better lifetime for nodes using WiseMAC. Seong-cheol Kim *et al.* [6] improved the throughput and end-to-end packet delivery ratio using modified IEEE 802.15.4 Beacon frame.

PROPOSED WORK

In this section, we provide the details of the proposed CSMA/Shortest Data First (SDF) an energy efficient MAC protocol, to improve the network lifespan.

1. CSMA/SDF:

The key idea of CSMA/SDF is to allow nodes with shortest data first finish their transmission so that they do not need to continuously sense the channel for long time if any node with large data is performing transmission. As a result, energy cost of carrier sensing of these nodes is reduced which in turn minimizes the WSN's overall energy cost and maximizes network lifetime. CSMA/SDF is a modification of the existed CSMA/CA MAC protocol. While CSMA/CA is complete contention-based, CSMA/SDF provides high priority to nodes with shortest data by implementing a Distributed Shortest Data First Scheduling Algorithm. CSMA/SDF also introduces an Anti-Starvation mechanism which allows nodes with long data also participate in transmission. CSMA/SDF also improves channel utilization by reducing the probability of occurrence of collisions.

2. *Channel contention in CSMA/CA and CSMA/SDF*

Suppose node1 needs to transmit 1packet and node2 needs to transmit 3 packets. Because of CSMA/CA's completely contention-based behaviour, there is a possibility of occurrence of high probability of collision. Channel contention in CSMA/CA is given in figure 3. Whenever collision occurs, CSMA/CA uses randomly back-off mechanism to reduce probability of collisions. In CSMA/CA, the total carrier sense rounds are 10,out of which 5 are of node1 i.e. time slots 2,4,5,7,8 and 5 of node2 i.e. time slots 1,2,4,5,7. Whereas in CSMA/SDF, nodes with shortest data are given higher priority during transmission. Channel contention in CSMA/SDF is given in figure 4. The total carrier sense rounds are 6, out of which 2 are of node1 i.e timeslots 2, 3 and 4 of node2 i.e.1, 2, 4, 5 slots.

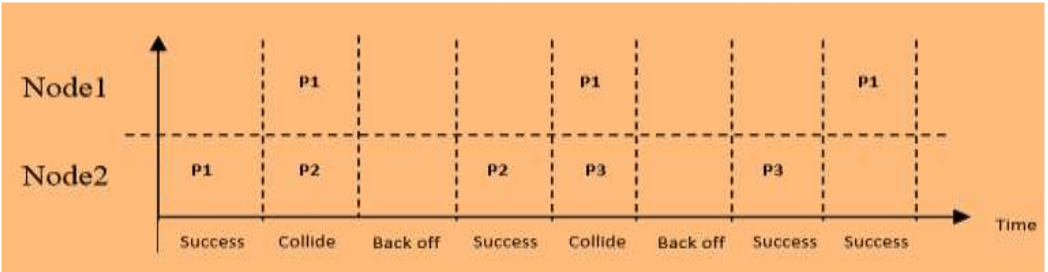

Fig. 3 Channel contention in CSMA/CA.

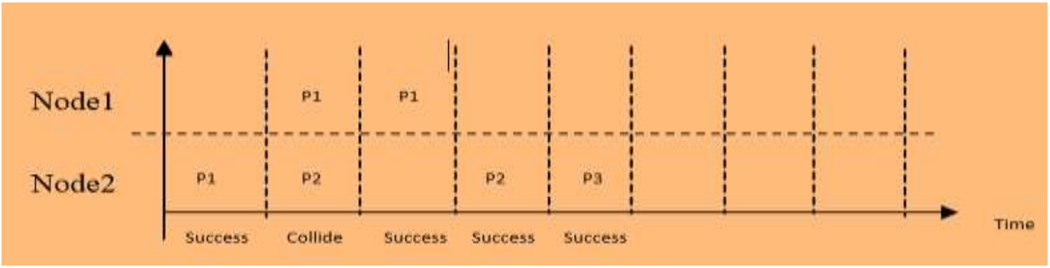

Fig. 4 Channel contention in CSMA/SDF.

From Fig. 3, completion of whole transmission in CSMA/CA costs 8 time slots whereas in CSMA/SDF it needs only 5. This is because, implementation of Shortest Data First scheduling algorithm reduces the time wasted in randomly back-off when collision occurred. As CSMA/SDF is priority-based instead of complete contention-based like in CSMA/CA, it reduces the probability of collision. Less collision means less control time wasted which in turn improves channel utilization. The main components of CSMA, SDF protocol are

- Distributed Shortest-Data-First Scheduling Algorithm
- Anti-starvation mechanism

3. Distributed shortest-Data-first scheduling algorithm

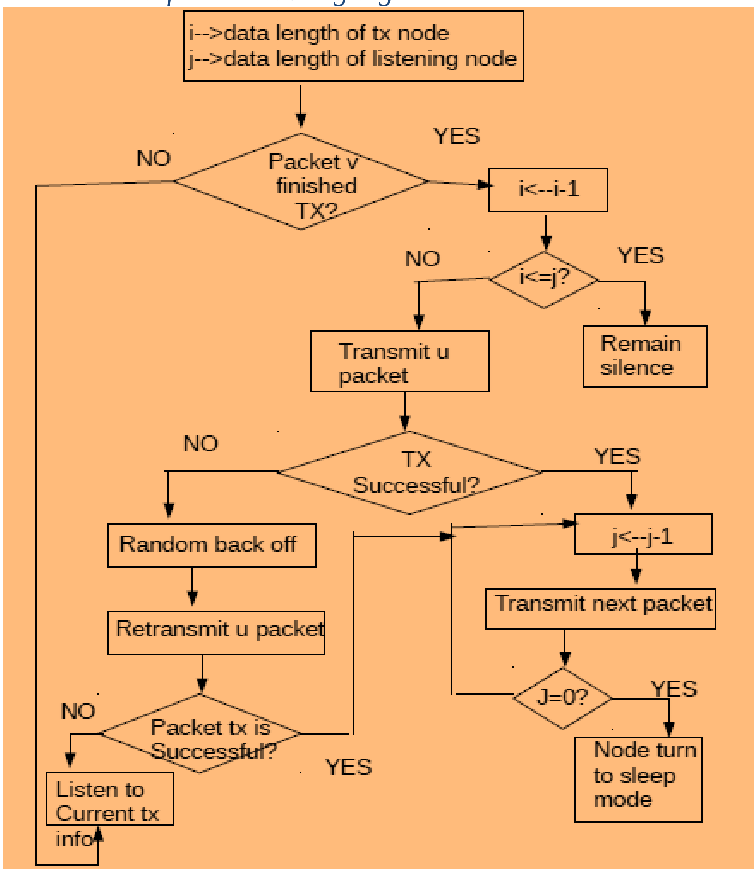

Fig. 5 Flow Chart of Distributed Shortest Data First Scheduling Algorithm.

The flow chart of distributed shortest data first scheduling algorithm is depicted in figure 5. Let 'i' represents the remaining data length of current transmitting node, which is listened by the sensing node. 'j' represents the remaining data length of the listening node itself. Packet v is the instantaneous packet that the transmitting node transmits, whereas packet u is the newly channel-accessed node's first remaining packet. From Fig.4, when the first collision happens in time slot 2 during node2's transmission of second packet P2, as distributed shortest data first scheduling algorithm is implemented, node2 knows that the collided node has less number of packets to transmit. Thus, node2 instead of contending for channel access, it turns into listening node.node1 senses that channel is idle, it transmits its packet P1 and turns into sleeping mode. After that, node2 senses channel is idle and finish its transmission.

4. Anti-Starvation Mechanism

As shortest data is given higher priority, nodes with long data will starve for channel access and cannot transmit its data for very long time. To solve this starvation problem, a periodical transmission mechanism called Anti-Starvation mechanism is added to CSMA/SDF MAC protocol. In this mechanism, a time-out is set as threshold value. When a node has not transmitted its data for a long time i.e. beyond threshold value, the anti-starvation mechanism is enabled and this node will be given highest priority in channel contention and is allowed to transmit some of its packets.

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5. CSMA/SDF Protocol:

```
1: for i ← remaining data length of transmitting node;
j ← remaining data length of listening node;
        packet v of Tx node finished transmission do
2:      i ← i − 1;
3:      compare i and j;
4:      if i ≤ j then
5:              listening nodes remain silence and allows Tx node to transmit;
6:      else
7:              Transmit u packet of listening node.
8:              if transmission is successful then
9:                      j ← j − 1;
10:                     if j = 0 then
11:                             node turns into sleeping mode;
12:                     else
13:                             i=j;
14:                             go to step 1
15:                     end if
16:             else
17:                     randomly back-off;
18:                     re-transmit u packet;
19:                     if transmission is successful
20:                             go to step 9
21:                     else
22:                             listen to current transmission information
23:                     end if
24:             end if
25:     end if
26: end for
```

PERFORMANCE EVALUATION

We evaluated the proposed scheme using a discrete event network simulator, ns2.35 on UBUNTU 12.04 LTS 64 bit Operating System. We present the effectiveness of the scheme over CSMA/CA in figures 6- 12.

i. Carrier Sense Time

Previously, it was proved that total energy consumption is proportional to time for which the node is in active state or in sensing state. So,

$$E_{CS} \propto T_{CS}$$

From the graph, it is clear that with increase in packet size, time taken for carrier sensing or the time in which the node is in active state increases. But, when compared to CSMA/CA, CSMA/SDF protocol implementation results in less carrier sensing time. As carrier sensing time decreases, energy required for sensing decreases which in turn decreases overall energy cost. Thus energy efficiency is increased.

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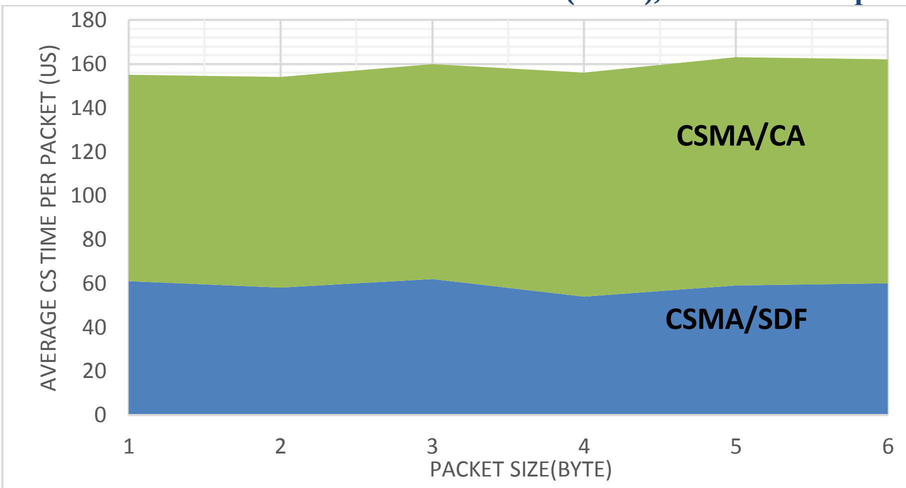

Fig. 6 Carrier sense time comparison between CSMA/CA and CSMA/SDF.

ii. *Throughput*

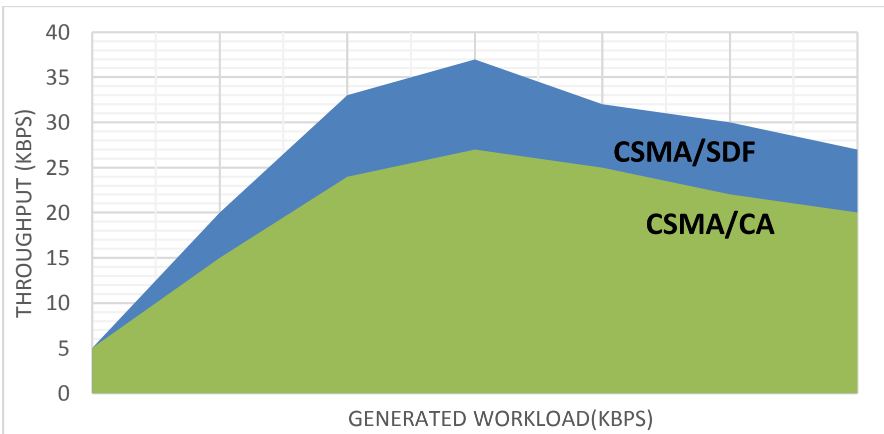

Fig. 7 Throughput comparison between CSMA/CA and CSMA/SDF.

From the graph, it is evident that when compared to CSMA/CA, CSMA/SDF has high throughput. The workload is generated from 0 to 200 bytes with an M time slot round, so that at any instant, the node with shortest data is given high priority. Also, as carrier sensing time decreases in CSMA/SDF and energy consumption is decreased, node or network lifetime is increased and number of successful message transmissions are increased.

iii. *Channel Utilization Efficiency Analysis*

The theoretical analysis for how CSMA/SDF can improve channel utilization when compared with traditional CSMA/CA MAC protocol.

$$\varepsilon_p = Np_1(1-p_1)^{N-1} + Np_1(1-p_1-p_2)^{N-1} + \dots + Np_M(1-p_1-p_2 \dots - p_M)^{N-1}$$

iv. $$= N\sum_{k=1}^{M} p_k \left(1-\sum_{x=1}^{k} p_x\right)^{N-1}$$

Let M be the number of slots and N be the number of nodes that contend for channel access. Let k be the slot number whose value ranges from 1 to M. Let p (i.e.p_1,p_2, ... p_M)The probability of selecting slot 1 is p_1, slot 2 is $p_2$and so on. Let $\varepsilon_p$be the probability of picking a slot successfully by all N nodes under the probability distribution p.

Consider the first part of above equation (i.e. $Np_1(1-p_1)^{N-1}$). Here $p_1(1-p_1)^{N-1}$ is the probability of successfully picking slot 1 (i.e. p_1) while other N-1 nodes fail to pick slot 1 (i.e. $(1-p_1)^{N-1}$).As all nodes are homogenous and have same probability of successfully picking a slot, the total probability of successful transmission ε_p can be written as $Np_1(1-p_1)^{N-1}$.

In CSMA/SDF, as shortest data is given higher priority, nodes with long data will not try to contend for channel access. Thus, the number of nodes that contend for channel access reduces. As a result, number of collisions decreases which

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conserves the power wasted during retransmissions when data is lost due to collisions and also, channel utilization is also increased.

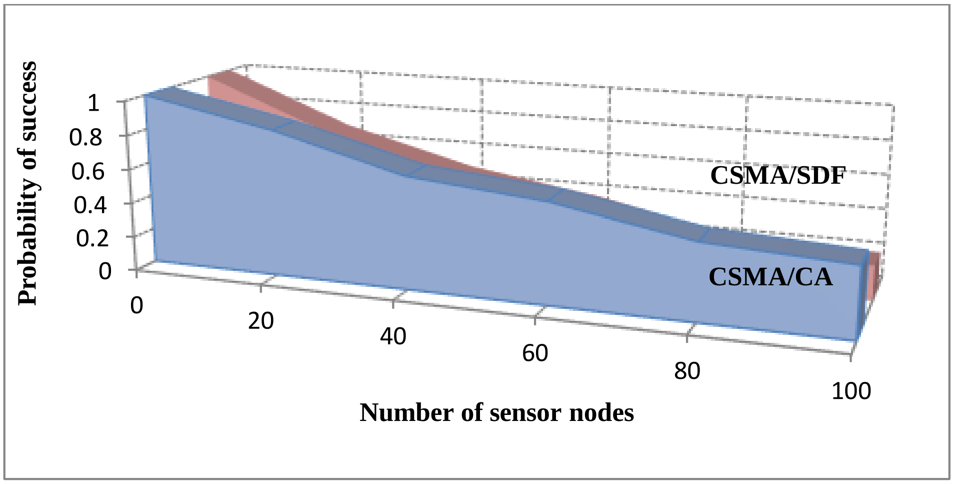

Fig. 8 Probability of success of channel access comparison between CSMA/CA and CSMA/SDF.

v. Average power consumption

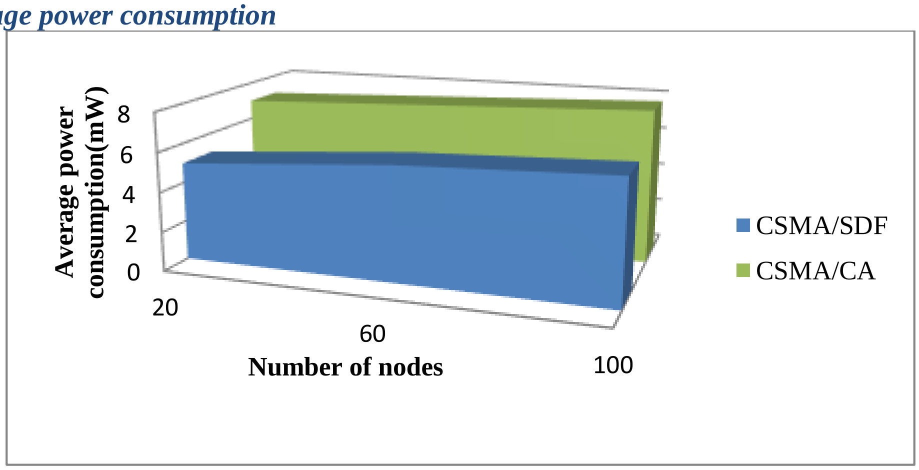

Fig. 9 Average power consumption comparison between CSMA/CA and CSMA/SDF.

From the graph, it is evident that with increase in number of nodes, the average power consumption is relatively less when compared with traditional CSMA. Thus in turn, enhances the network lifetime

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vi. Throughput under varying number of nodes

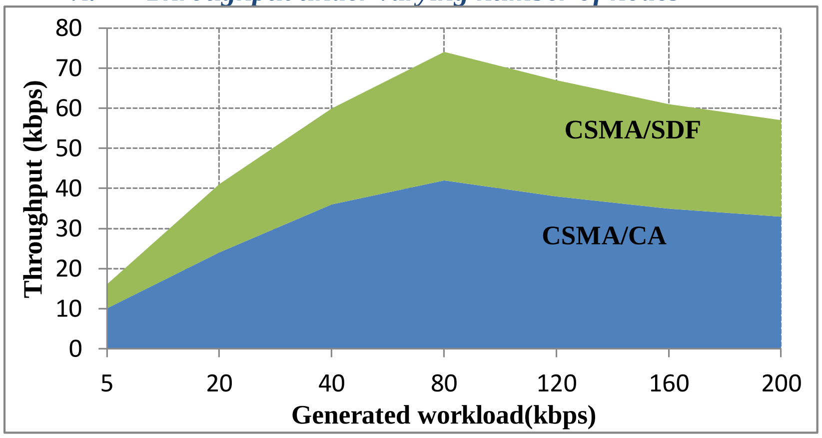

Fig. 10 CSMA/SDF throughput performance with 20 nodes.

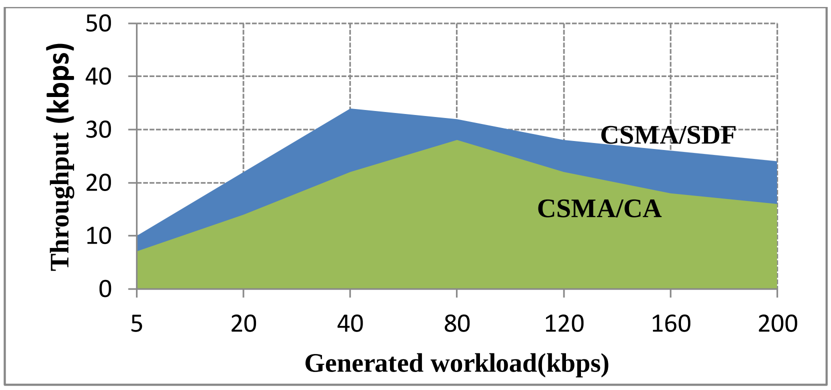

Fig. 11 CSMA/SDF throughput performance with 60 nodes.

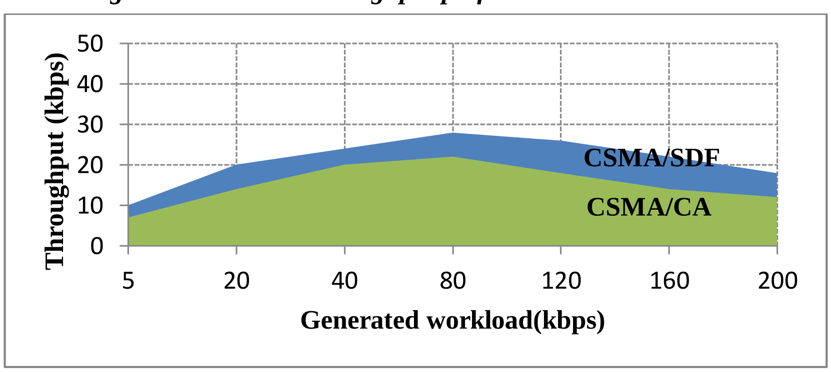

Fig. 12 CSMA/SDF throughput performance with 100 nodes.

Above are the figures plotted against throughput and generated workload under three different conditions, i.e. with 20, 60, 100 nodes respectively. In each condition, CSMA/SDF has higher throughput compared to CSMA/CA. With increase in number of nodes, throughput is decreased in both CSMA/SDF and CSMA/CA. As number of nodes increases, network size increases and nodes need to spent more energy to transmit from source to sink. As a result, nodes may lose their energy very fast and die resulting in decrease in network lifetime. At this position also, at 100 nodes, CSMA/SDF has higher throughput than CSMA/CA which implies increase in network lifetime. The comparative analysis is given in Table 1.

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Table 1. Comparative Analysis of Performance metrics.

Performance metric	CSMA/SDF vs CSMA/CA
Carrier Sense time	Decreased by 42%
Probability of Success	Increased by 46%
Energy consumption	Decreased by 24%
Throughput	Increased by 36%

CONCLUSION

We proposed a CSMA-SDF, an efficient Carrier Sensing Scheme to improve the lifespan of Wireless Sensor Networks. This new MAC protocol CSMA/SDF minimizes energy cost in carrier sense process. To achieve this, a distributed shortest-Data-First algorithm and Anti-Starvation mechanism are used. We modified the existing CSMA/CA by introducing a priority that is the node with shortest data is given higher priority during channel access contention. The distributed shortest-Data-first algorithm is used to allow shortest-Data-first scheduling process in distributed manner. Anti-Starvation mechanism is used to solve the starvation problem of longer data nodes, caused when nodes with shortest data are given high priority to access the channel. The simulated results of CSMA/SDF proves to be efficient over CSMA/CA by reducing carrier sense time by 42% and overall energy cost by 24% and improving channel utilization up to 46% and throughput by 36%.

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