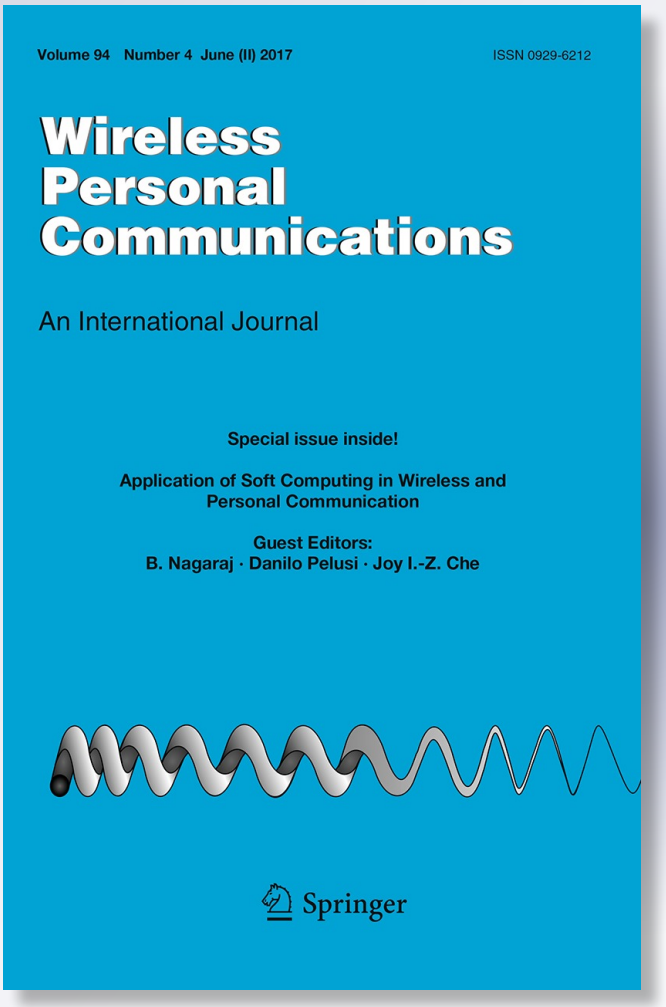
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Spatial Correlation Based Cross Layer Approach with Routing in Wireless Sensor Networks

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Abstract Wireless Sensor Networks (WSNs) are more popular due to the use of low cost sensors with their interfaces. In designing of WSNs, energy conservation is a main issue. The nodes available in WSNs use battery as limited energy source. Various techniques have been proposed to improve the energy efficiency in WSNs. Energy efficient Medium Access Control (MAC) protocol is required for obtaining higher energy efficiency during difficult operating conditions, where node failure and link failures are common. Cross layer approach between data link and network layer is adapted in the proposed work. In the proposed work, the MAC protocols such as Correlation based Collaborative MAC (CC-MAC), CC-MAC combined with Hybrid MAC, Hybrid MAC, Hybrid MAC combined with sensor MAC have been considered for analysis. Two popular routing protocols such as Ad hoc On-demand Distance Vector, Ad hoc On-demand Multipath Distance Vector are also considered to identify the routing performance of the network. The Parameters such as end-to-end delay, packet drop, packet delivery ratio, throughput, energy efficiency are considered to measure the network performance. These parameters are acting as a primary and secondary attributes to design an efficient MAC protocols for WSNs.

Keywords Ad hoc On-demand Distance Vector (AODV) · Ad hoc On-demand Multipath Distance Vector (AOMDV) · Correlation based Collaborative MAC · CC-MAC combined with Hybrid MAC · Hybrid MAC · Hybrid MAC combined with sensor MAC · Energy efficiency · Medium access control (MAC) · Wireless Sensor Networks (WSNs)

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1 Introduction

Wireless Sensor Network (WSN) is designed to detect events or phenomena, collect and process data, transmit sensed information to the destination user. To minimize energy consumption during the network activity, different energy efficient protocols are designed. Medium Access Control (MAC) protocols help to achieve higher energy efficiency during long idle period of the sensors in WSNs. Energy efficiency, network control and management are the primary concern in the design of MAC protocol [1]. Transmitting and receiving operations consume considerable amount of energy. For these issues, energy efficient MAC protocols are designed. Signaling overhead is minimized and idle listening is also avoided. Link quality is measured in WSNs through weighted regression algorithm [2]. The quality of a link to its corresponding neighbor is identified. The variance value of the link with respect to time and spatial locations are considered to evaluate the algorithm. The major flaw is size of the window and non-inclusion of the number of classes. The weighted regression algorithm is not explored in cross and different system layers. Spatial correlation based Collaborative Medium Access Control Protocol (CC-MAC) designed with two components such as Event MAC and Network MAC protocols is proposed [3]. These protocols are useful to filter out the redundant data and to prioritize the transmission of routes through packets. The exploitation of spatial correlation on MAC layer is discussed. The drawback of this work is that only one type of phenomenon can be sensed by the sensor nodes. For multiple type of traffic in WSNs, CC-MAC protocol cannot be modified using multiple correlation radius values. Cluster protocol based energy aware spatial correlation is proposed [4]. Only cluster heads are responsible for exploitation of spatial correlation between the member nodes. Distortion and tolerance are the two parameters which are responsible for correlation. The correlation region can be resized according to distortion and tolerance. These parameters can be measured by sink node.

Related work is briefly discussed in second section. In third section, proposed model is discussed. Fourth section discusses spatial correlation method. In fifth section, results are discussed in detail and comparison with other MAC protocols has been done based on various parameters. Conclusion and future work are discussed in final section.

2 Related Work

Different ways of selecting sensor nodes and spatial correlation based MAC protocol known as SCMAC is investigated [5]. SCMAC protocol adopts priority node selection algorithm and collision avoidance mechanism to prevent redundant data transmission and reduces energy consumption. The drawback of this work is that only one type of MAC protocol is proposed. The usage of sensing coverage of nodes in determining the correlation characteristics of sensor node is discussed [6]. The concept of spatial correlation inside the event area is exploited through C-INS algorithm. The energy efficiency and end-to-end delay is improved through this algorithm. C-INS algorithm is designed in distributed aspect to achieve lower overhead and it is not combined with any of the routing protocols. A new MAC protocol scheme to extend the network lifetime and also to achieve lowest energy consumption and transmission delay is proposed [7]. The new MAC protocol is combined with ring shaped spatial correlation model which increases data transferring efficiency. The drawback of this work is that MAC protocol concept is not

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combined with any of the routing protocols. The important MAC protocols to analyze the source of energy wastage during data transmission and reception is discussed [8].

Several MAC protocols related to WSNs and their advantages and disadvantages are discussed. Issues and difficulties in the design aspects of MAC protocols are also discussed. An algorithm named dYnamic and Scalable tree Aware of Spatial Correlation (YEAST) algorithm to achieve betterment in aggregation quality and enhance load balancing support is discussed [9]. The maximum amount of residual energy of each individual node is saved through their algorithm. Routing scheme is adapted and spatial correlation mechanism is used to save the energy of the nodes. This is done to achieve energy aware data forwarding inside the network. Spatial correlation region cannot be changed dynamically to know the details of the sensed information. Different sizes of the correlation region are also not considered. To take care of the challenges in Energy Efficient Spatial Correlation based Networking Protocols for WSNs, an energy efficient analysis of CC-MAC (Correlation based Collaborative MAC), CCHMAC (Correlation based Collaborative MAC combined with Hybrid MAC), Hybrid MAC (HMAC), Hybrid sensor MAC (HSMAC) for WSNs are proposed. At MAC layer, energy efficiency is achieved through the minimization of idle listening, retransmission, unwanted overhearing, over emitting. Certain real time MAC protocols are specifically designed for WSNs. Real time MAC is divided into Hard real time and Soft real time MAC protocols [10].

Energy efficiency, packet loss, throughput, latency, packet delivery ratio are the parameters used to measure the network performance. Each node in WSNs operates on a limited battery power. Two broad categories of energy consumptions in WSNs are Useful energy source and Wasteful energy source [11]. The information can be easily shared among different protocol layers for adaptation purposes and to increase the inter-layer interactions through the cross layer [12]. WSNs are utilized in a wide range of applications such as battlefield surveillance, zebranet, habitat monitoring, disaster detection, asset monitoring and management, urban planning, disaster recovery, self-healing minefield, medical sensing, micro surgery and many more [13]. Time Division Multiple Access (TDMA), Dual mode, Message ordering, traffic management are the categories of hard real time MAC. Sensor MAC (S-MAC), spatial channel reuse, energy aware are the further classifications of Soft real time MAC. Four different types of MAC protocols are available for WSNs. They are contention based, scheduling based, collision free and hybrid MAC protocols [14]. The objectives of MAC protocols are collision avoidance, energy efficiency, scalability, latency, fairness, throughput, bandwidth utilization. High density of nodes and increased collision probability may occur in WSNs architecture. To prevent further collisions, signaling overhead should be minimized and also the design of collision avoidance protocol is necessary. When the sensor node fails to work, the performance of the network and connectivity is affected. Transmitting and receiving operations consume considerable amount of energy. For these issues, energy efficient MAC protocols are designed and signaling overhead is minimized and idle listening is also avoided [15]. MAC protocol shares limited communication resources efficiently between the nodes [16]. The MAC protocol manages radio transmissions and receptions on a shared wireless medium. MAC has a very high effect on network performance and energy efficiency.

User-oriented load balancing scheme for an energy-efficient load balancing in wireless networks is proposed. The proposed scheme is based on allocation of load on wireless sensor nodes proportionally to each of the agent's capacity and user-oriented approach. Mathematical analysis is also proposed [17]. To improve the energy consumption in a multihop WSNs (MhWSN), cross layer based approach is proposed. A cross-layer and hybrid energy efficiency protocol (CL–HEEP) with transmission power adjustment is used

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to preserve the energy reservation in multi-hop MhWSN [18]. Use of routing information to dynamically adjust the transceiver transmission power and to establish cross-layer duty-cycling is the main contribution of this work. They are top-down, bottom-up, application centric, MAC centric and integrated approach. In the proposed work, Cross layered approach is adapted between data link and network layer to achieve energy efficiency related issues [19].

S-MAC includes periodic listen and sleep and collision and over hearing avoidance and message passing. The energy waste caused by idle listening is reduced by sleep schedule in S-MAC [20]. One of the important aspect of WSNs is Cross Layer Design (CLD). CLD of WSNs is useful to exchange information between non-adjacent layers. CLD enhanced the performance of the nerwork and also quality of service. Various CLD methodologies for WSNs are discussed along with network performance [21]. The link layer protocols such as S-MAC, DRAND and Z-MAC protocols are compared. Based on the parameters such as power consumption, traffic rate, propagation channel resources, the performance is evaluated. Sensor nodes are randomly placed for experimentation purpose and also to analyze the network performance [22].

3 Proposed Model

Spatial correlation based Cross Layer Approach with Routing is proposed. The proposed model uses spatial correlation as a primary mechanism in WSNs field. Spatial correlation is adapted as a key technique to analyse WSNs field and the report collected by sensor nodes in the regions available in the WSNs field [23].

3.1 Cross Layer

The cross layer information exchange is shown in Fig. 1. It consists of five layers which are available in protocol stack and all the layers are connected to cross layer information exchange.

The layered protocol stack is inflexible and hard. Each layer in the protocol stack concentrates on the layer directly above it and the layer below it. This leads to non-collaborative design between different layers known as the cross layer design. The objective of cross layer design is to exploit information from multiple layers to jointly optimize the performance of the layers [24]. The information can be easily shared among different protocol layers for adaptation purposes and to increase the inter-layer interactions

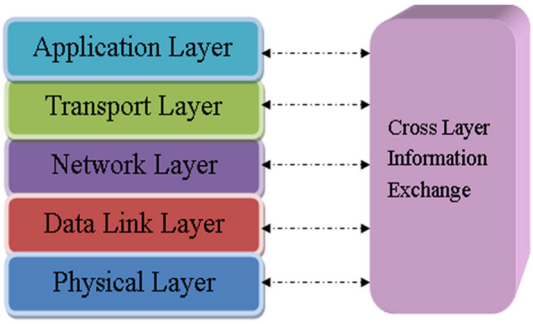


Fig. 1 Cross layer information exchange

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through the cross layer [12]. The breaking of hierarchical layers or the violation of reference architecture includes merging of layers, creation of new interfaces or providing additional interdependencies between any two layers [25]. Cross Layer optimization is broadly classified into several categories based on the order in which optimization is performed [26]. Optimization of multiobject QoS in cross layer is discussed [27]. In physical layer a link quality estimator has been used for the purpose of evaluating link quality. In MAC layer, a QoS enhanced MAC algorithm is adapted for allocating more number of channels to avoid critical traffic. In the network layer, routing algorithm is used for multiobject QoS optimization. Due to the cross layer structure, there is improvement in the parameters such as end-to-end reliability and latency, link quality, wireless channel contention.

3.2 Correlation Based Collaborative MAC (CC-MAC) Protocol

The proposed work deals with Correlation based Collaborative MAC protocol (CC-MAC). CC-MAC aims to prevent transmission of redundant information from sensor node to representative node and also from representative node to sink node. It performs prioritization of the filtered data and forwards it to the sink. Figure 2 introduces the structures of RTS, CTS, data packet. CC-MAC protocol contains two components, initiate MAC and route MAC corresponding to the source and router functionalities [3]. Initiate MAC (I-MAC), filters out the correlated records. Route MAC (R-MAC) ensures prioritization of route-through packets. Both I-MAC and R-MAC use a CSMA/CA based MAC with appropriate modifications. The information about correlation formation is embedded inside the RTS/CTS/DATA/ACK packets.

Each node is informed about the correlation information about a node using these packets. A node performs I-MAC when it has to transmit its sensor reading to the sink and R-MAC is performed when a node receives a packet and tries to forward it to the next hop.

3.3 Sensor MAC (S-MAC)

S-MAC is a contention based protocol proposed for energy constraints in a network. S-MAC protocol provides mechanism to get around Idle listening, Collisions, Over hearing. It adopts a periodic wake up scheme, i.e., each node alternates between a fixed length listen period and fixed length sleep period.

Fig. 2 Structure of RTS, CTS, data packet

RTS Packet Structure

Frame Control	Duration	RA	TA	FH	FCS
Bits 16	16	48	48	1	32

CTS Packet Structure

Frame Control	Duration	RA	FH	FCS
Bits 16	16	48	1	32

Data Packet Structure

MAC Header	FH	Frame Body	FCS
Bits 240	1	0-18496	32

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In S-MAC, nodes form virtual clusters with common sleep schedule, so all the clusters wake up and start communicating at the same time. The channel is divided into an active period and sleep period. The active and sleep period of S-MAC protocols has been shown in Fig. 3 for three different number of nodes.

3.4 Hybrid MAC Protocol (HMAC)

HMAC protocol reduces energy wastage and provides better quality of service. HMAC has time synchronization [28] and full duplex communication. HMAC has the ability to adapt according to the environmental conditions. Applications of HMAC include one hop broadcast mechanism and converge cast. For various network conditions, HMAC improves channel utilization and latency. HMAC introduces the concept of slotted frame structure. In slotted frame structure, slot for individual frames are dynamically shared. HMAC Hello Packet structure is given in Fig. 4.

In Figs. 5 and 6, Schedule packet and data packet of HMAC protocol are shown.

Figure 7 shows scheduled and unscheduled slots of HMAC protocol. N_S represents scheduled slots in HMAC and N_U represents unscheduled slots in HMAC protocol. Scheduled slot shares state information whereas unscheduled slot adjusts based on state information received from scheduled slot. HMAC is similar to S-MAC with only one difference i.e., in sleep time. HMAC is similar to S-MAC with only one difference i.e., in sleep time. Therefore in the proposed system, these two protocols are considered for comparison with CC-MAC and also to form new MAC protocols such as CCHMAC and HSMAC.

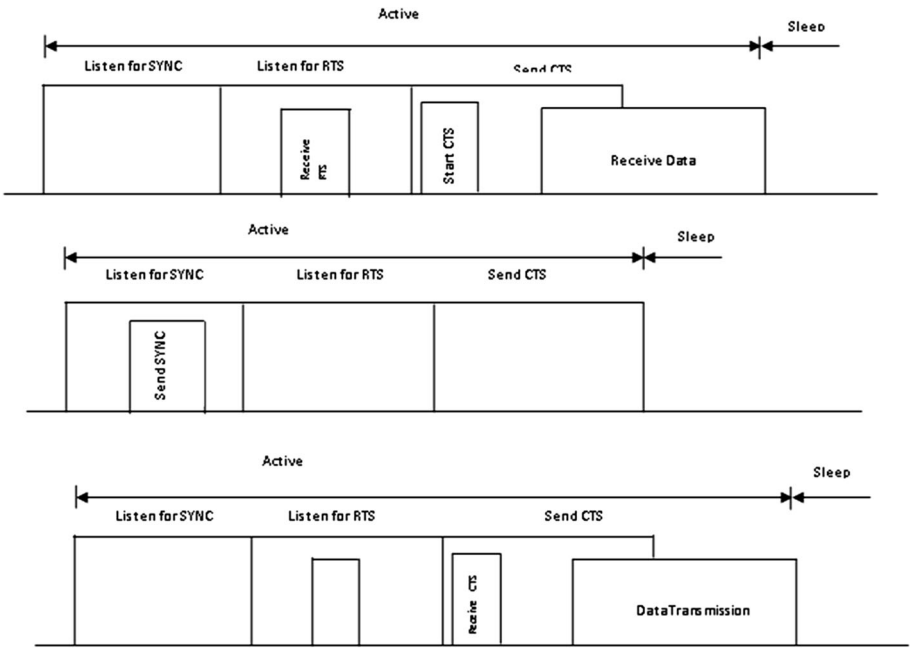


Fig. 3 Active and sleep period of S-MAC protocol

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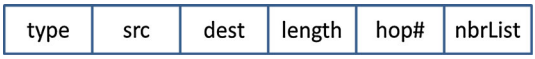


Fig. 4 HMAC hello packet structure

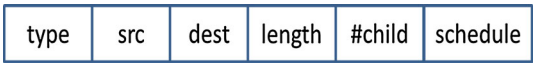


Fig. 5 Schedule packet of HMAC protocol

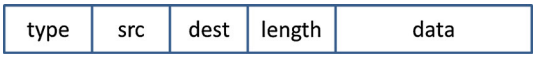


Fig. 6 Data packet of HMAC protocol

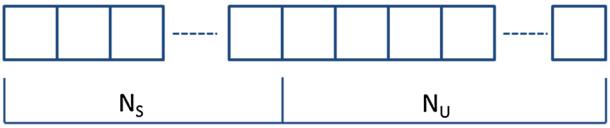


Fig. 7 Scheduled and unscheduled slots of HMAC protocol

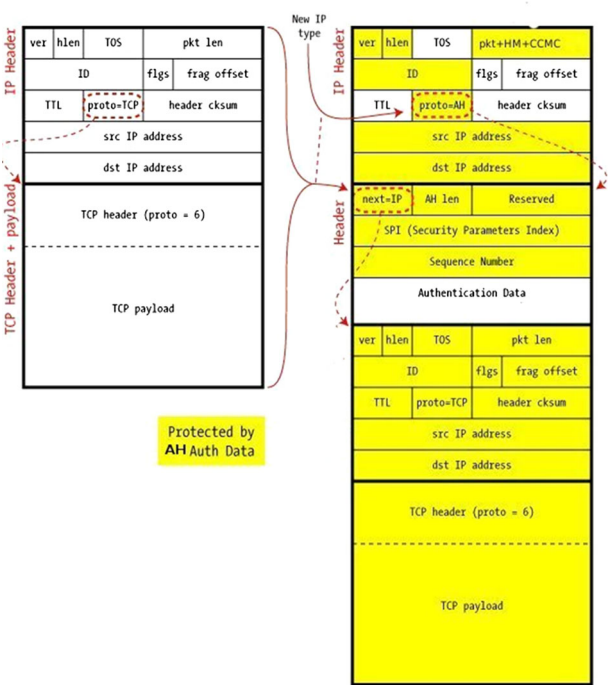


Fig. 8 Format for CCHMAC

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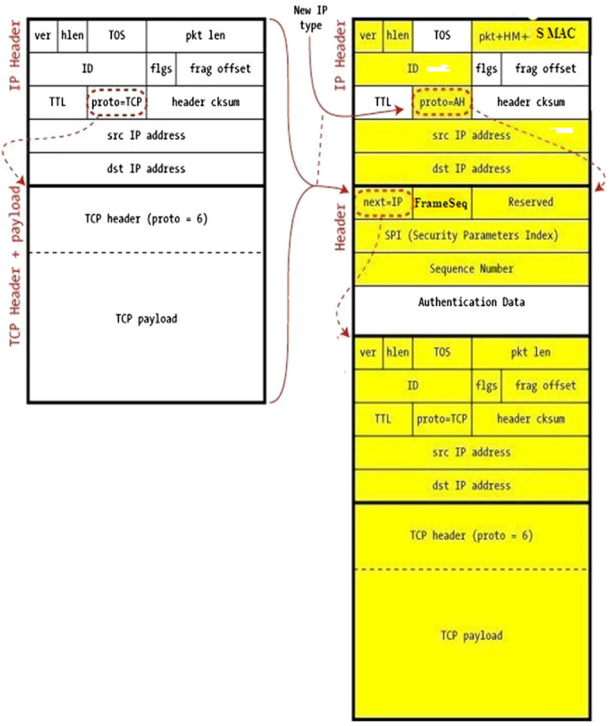


Fig. 9 Format for HSMAC

Format of CCHMAC and Format of HSMAC protocols are given in Figs. 8 and 9. In the above figure, Ver represents version of the protocol. hlen refers IP Header length, as a four-bit number of 32-bit words ranging from 0,…,15. TOS represents Type of Service. This field is a bitmask that gives some clues as to the type of service this datagram should receive. pkt len is a overall packet length in bytes, up to 65,535. ID field is used to associate related packets that have been fragmented (large packets broken up into smaller ones). flgs are small flags that mainly control fragmentation. frag offset is useful to identify packet's fragmentation among the overall virtual packets. TTL is the Time to Live and is decremented by each router that passes this packet. Proto represents the protocol carried within this packet, and it's going to be central to most of our discussions. Header cksum holds a checksum of the entire IP header and it's designed to detect errors in transit. Src IP address is a 32-bit source IP address, which the recipient uses to reply to this datagram. dst IP address is the 32-bit destination IP address, which is where the packet is intended to arrive.

IP Options are an optional part of the IP header that contains application-specific information, though they are not commonly used for routine traffic. Payload implies its own format for what follows the IP header. Next hdr identifies the protocol type of the following payload, and it's the original packet type being encapsulated. AH len defines the length, in 32-bit words, of the whole AH header, minus two words. Reserved field is reserved for future use and must be zero. Security Parameters Index is an opaque 32-bit identifier that helps the recipient select which of possibly many ongoing conversations this packet applies. Sequence Number is a monotonically increasing identifier that's used to

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assist in antireplay protection. Authentication Data is the Integrity Check Value calculated over the entire packet.

3.5 TRaffic Adaptive Medium Access Protocol (TRAMA) and Receiver Initiated MAC (RI-MAC)

TRaffic Adaptive Medium Access protocol is abbreviated as TRAMA. TRAMA is a single time slotted channel access protocol. Its scheduling is based on one-hop traffic information and two-hop neighborhood information. Two types of access periods are available in TRAMA. They are Random access period and scheduled access period. Random access period is used for signaling and scheduled access period is used for contention free data exchange among the nodes. Channel access scheme in TDMA is based on distributed TDMA. To achieve energy efficiency, radio mode control is used in TRAMA. Due to its transmission schedule, the battery life time is extended. TRAMA is robust to wireless losses. Receiver Initiated MAC (RI-MAC) uses receiver initiated data transmission in order to efficiently and effectively operate over different traffic load conditions [29]. RI-MA C decouples the duty cycle of sender and receiver and also find a time to exchange the data between sender or receiver. Compared to other protocols, RI-MAC achieves higher throughput, higher packet delivery ratio, higher energy efficiency under various traffic load condition. Due to this features RI-MAC and TRAMA are compared with the proposed MAC protocols.

4 Spatial Correlation Method

Initially WSNs field are divided as several correlation regions. Each correlation region consists of one representative node and several sensor nodes to collect the data. Main task of the representative node is to collect the report from its sensor node and inform the details with master node belonging to the WSNs field. Redundant data is possible when the report is collected by representative nodes from its subordinate nodes. Therefore filtering the redundant data is necessary before it reaches the master node of the corresponding region. Similarly, redundancy in the collected report is also applicable at the master node. It is necessary to filter the similar reports submitted by neighborhood representative nodes

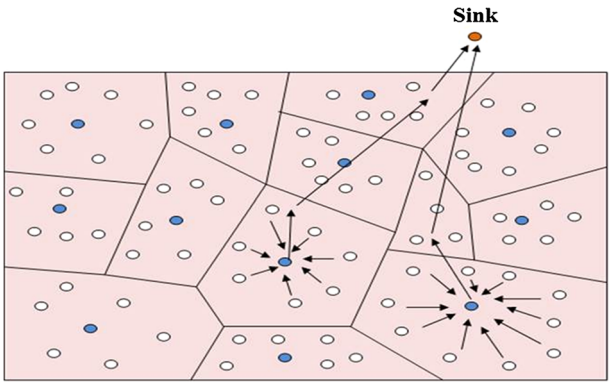


Fig. 10 Representation of correlation region

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nearer to the event field in WSNs. Reducing the redundant report leads to life time maximization of the WSNs. The spatial correlation region is defined as the region in which all the sensor nodes send the readings which are similar in nature and therefore it is enough

Fig. 11 Pseudo code for spatial correlation based cross layer approach with routing

```
/*Spatial Correlation based Cross Layer Approach with
   Routing */
S1 ← Set 1;
P ← Correlation of the node;
d ← Distance of the node ;
Rn1 ← Representative nodes;
REn ← Highest residual energy of the representative
      node;
a^2 ← Variance of the nodes;
PE ← Power Exponential model;
g1 , g2 ← Parameters to control P and d;
CR1 ← Correlation radius of S1;
CV ← Covariance function of S1;
tsBn ← Sleep time period of the nodes Bn;
ttBn ← Transmission period of the nodes Bn;
tNBn ← Next transmission time of the period tNBn ;
While ( Event is occurred in S1)
{
 Bn ← Calculate the total number of nodes in S1 ;
 Rn1 ← Calculate the total number of representative nodes
  in S1;
 CR1 ← Calculate the correlation radius of S1 ;
Store the position of sink node and neighbor nodes of S1;
Calculate weight of the each node w.r.t Sink, W(Bn,Sk) =
REn / d(Bn, Sk) ;
B2 is the correlation neighbor of B1 when d(B1,B2) < CR1;
Check REn of representative nodes in S1;
Calculate d1,2 ← Pm1-Pm2 ;
Calculate P1,2 ← E[m1,m2] / a^2 ;
Calculate Cv^PE (d) ← e^(-d/g1)g2 ;
Collect the data from S1 through Rn1;
Calculate the redundant data among the nodes in each
 transmission;
Calculate the missing of data between B1 and B2 =
 |B1_miss∩ B2_miss| ;
Collect a single report if redundant report is identified and
send to Rn1;
Apply CC-MAC based AODV / AOMDV to route the data
from Rn1 to Sink;
Replace CC-MAC by CCHMAC/ HMAC/ HSMAC and do
route using AODV/AOMDV;
Check the residual energy of representative nodes;
If residual energy is very low replace the node with highest
RE among the nodes;
Node moves to tsBn when ttBn < tsBn< tNBn ;
Check for other event and repeat the same procedure in S1;
}
```

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to send a single report to represent the correlation region [3]. The representation for spatial correlation region is shown in Fig. 10.

Correlation between the nodes m_1, m_2 is given by Eq. 1,

$$\mathrm{Corr}\{m_1, m_2\} = P_{1,2} = C_v(d_{1,2}) = E[m_1, m_2]/a^2 \tag{1}$$

where $P_{1,2}$ is correlation coefficient, $d_{1,2}$ is distance between nodes m_1, m_2 is given in Eq. 2,

$$d_{1,2} = P_{m_1} - P_{m_2} \tag{2}$$

where m_1 and m_2 are the coordinates, $C_v(\cdot)$ is the covariance function.

Covariance function is assumed as positive and it is indirectly proportional to distance. Variance of the source is denoted as a^2.

$$Cv^{PE}(d) = e^{(-d/g_1)g_2} \tag{3}$$

PE denotes power exponential model. g_1 and g_2 are parameters in Eq. 3. When $g_2 = 1$ the model becomes exponential model. g_1 controls the relation between the two nodes m_1 and m_2. g_1 has the direct relation with correlation coefficient P and correlation distance d [3]. The proposed work is carried out using power exponential model.

Figure 11 shows the pseudocode for spatial correlation based cross layer approach with routing. Initially total number of nodes are calculated in set 1. Set 1 is assumed as one of the correlation region of WSNs field. The total number of representative nodes and correlation radius of set 1 are calculated. The position of the current node and its neighbor nodes and sink nodes are stored. The weight of each node is calculated based on its neighbor node. The highest residual energy of the representative node is calculated along with distance, correlation coefficient, covariance function between node 1 and node 2. When the event occurs, the data is collected from set 1 through the representative node, at the same time redundant data transmission and missing of data [30] between two adjacent nodes are also analyzed. If any redundant report is identified, a single report about the event is transmitted immediately to sink node through representative node. CC-MAC based AODV/AOMDV protocol is used to route the data to sink from the representative node initially. The residual energy of representative node is monitored, if it is zero after the transmission process then the next node inside set 1 with highest residual energy is considered as representative node. The same procedure is carried out for CCHMAC based

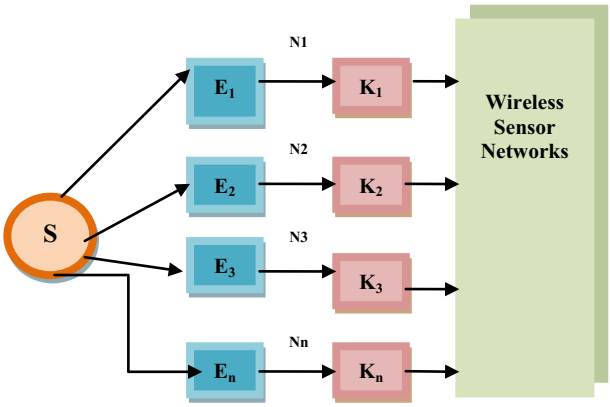


Fig. 12 Wireless Sensor Networks—encoder

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AODV/AOMDV and HMAC based AODV/AOMDV, HSMAC based AODV/AOMDV to route the data. The nodes in the network is in sleep period. When it is not involved in the transmission process.

When the next event occurs, the above mentioned steps are repeated.

A model for WSNs is shown in Fig. 12 Source node is represented as S. Total number of nodes available in an event area is M. Each node in the sensor field observes the noisy version of event information $K_i(n)$, S_i (n) and is spatially correlated to event source S. Each node has to encode its observation for the purpose of reporting event information to sink node. The sink is available at the other end which is responsible for decoding the information to get an estimated value of S′ [3].

In Fig. 12, the encoder part is labeled as E and the decoder part is labeled as D as given in Fig. 13.

At a time n, each observed sample is denoted as $K_i(n)$, equation is given in Eq. 4,

$$K_i[n] = S_i[n] + N_i[n] \tag{4}$$

where the symbol i denotes the spatial location of the node n_i, i.e. (x_i, y_i).

$N_i(n)$ is the observation noise, $\{N_i(n)\}$ is a sequence of i.i.d Gaussian random variables of zero mean and variance.

Each observation $K_i(n)$ is then encoded into Yi(n) by the source-coding at the sensor node is given by Eq. 5,

$$Y_i[n] = f_i(K_i[n]) \tag{5}$$

The information is transferred to the sink through the network. The sink on the other hand decodes the received data to reconstruct an estimation S′ of the source S is given by Eq. 6.

$$S' = g(Y_1[n_1], \ldots, Y_1[n_\tau]; \ldots . Y_N[n_1], \ldots, Y_N[n_\tau]) \tag{6}$$

5 Results and Discussion

Using Network Simulator 2 (NS2), the simulations have been simulated to model the WSNs and test the performance of spatial correlation based cross layer approach with routing. Various MAC protocols considered for the analysis are CC-MAC, CCHMAC,

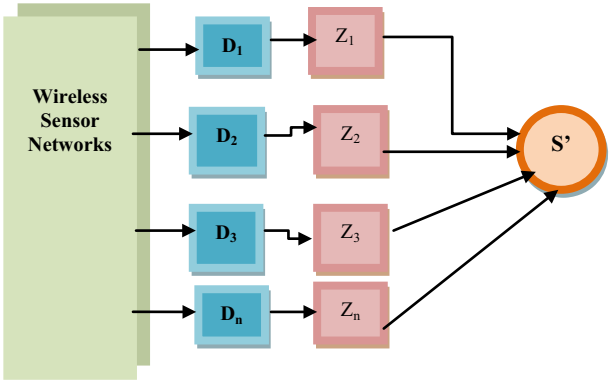


Fig. 13 Wireless Sensor Networks—decoder

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HMAC, HSMAC. In the proposed work, the routing protocols such as AODV, AOMDV are considered only to analyze the behavior of CC-MAC, CCHMAC, HMAC, HSMAC protocols. In the proposed work, the simulation run for 100 ms has been carried out. The Figs. 14–24 show the simulations 20 and 100 ms. Simulation time is started from 0 to 100 ms. To know the network performance exactly and accurately, at 20 and 100 ms range is considered. Network area of 1500 × 1500 m^2 is considered. Total no. of nodes are 100 with 100 m spatial correlation radius, 512 bytes of packet length, 100 J of initial energy, 2.4 GHz of bandwidth, 250 kbps with the transmitting and receiving power of 2 and 1 mW level of simulation parameters are considered. Output Parameters such as energy efficiency, end-to-end delay, packet drop, packet delivery ratio, and throughput are considered for the analysis. During the simulation, the initial energy is set to 100 J. The remaining energy in the node after the implementation of the proposed protocol is observed.

5.1 Comparison of End-to-End Delay with AOMDV Versus AODV

Figure 14 shows the comparison of end-to-end delay with time for the proposed CC-MAC, CCHMAC, HMAC and HSMAC based AODV protocols compared with CC-MAC, CCHMAC, HMAC and HSMAC based AOMDV protocols. At 100 ms, the proposed CC-MAC based AOMDV has an end-to-end delay of 0.84 ms less than the CC-MAC based AODV as CC-MAC based AOMDV has the ability to exploit spatial correlation on MAC layer and it searches for alternate routes when a current link breaks down. At 100 ms, the proposed CCHMAC based AOMDV has an end-to-end delay of 0.14 ms less than the CCHMAC based AODV as CCHMAC based AOMDV has the ability to create a route to destination only on demand but CCHMAC based AOMDV finds alternate route even if the current link is broken. At 100 ms, the proposed HMAC based AOMDV has an end-to-end delay of 0.54 ms less than the HMAC based AODV as HMAC based AOMDV works better fully supported duplex communication and loop freedom for a node is assured. At 100 ms, the proposed HSMAC based AOMDV has an end-to-end delay of 0.04 ms less than the HSMAC based AODV as HSMAC based AOMDV works better. The energy

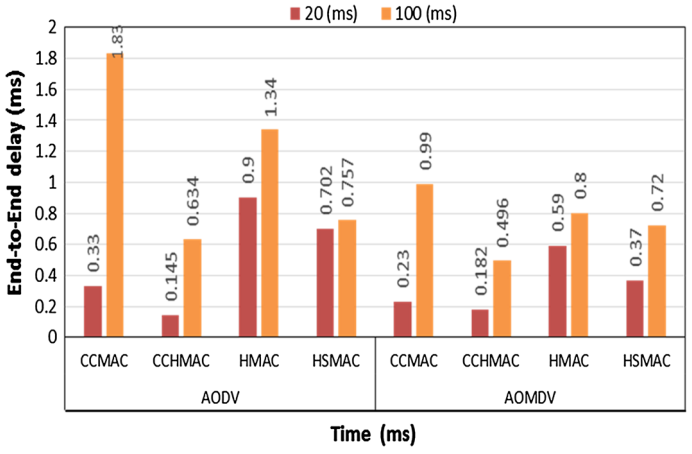


Fig. 14 Time versus end-to-end delay of CC-MAC, CCHMAC, HMAC and HSMAC based AODV versus CC-MAC, CCHMAC, HMAC and HSMAC based AOMDV

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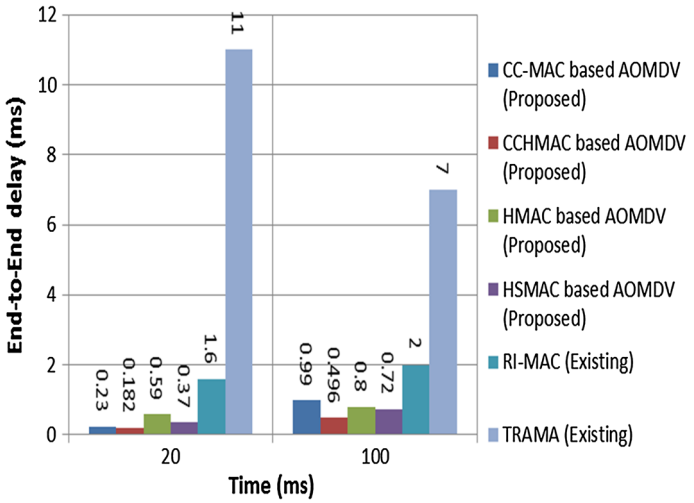


Fig. 15 Time versus end-to-end delay for various protocols

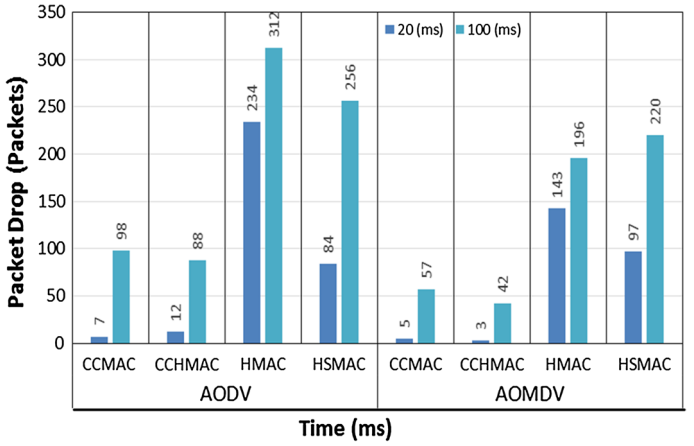


Fig. 16 Time versus packet drop of CC-MAC, CCHMAC, HMAC and HSMAC based AODV versus CC-MAC, CCHMAC, HMAC and HSMAC based AOMDV

waste caused by idle listening is reduced by sleep schedule and it is suitable for broadcast communication.

On an average, CC-MAC based AOMDV has 39.8 % lesser end-to-end delay value than that of CC-MAC based AODV. CCHMAC based AOMDV has 11 % lesser end-to-end delay value than that of CCHMAC based AODV and HMAC based AOMDV has 40 % lesser end-to-end delay value than that of HMAC based AODV. HSMAC based AOMDV has 26 % lesser end-to-end delay value than that of HSMAC based AODV.

Figure 15 shows the comparison of end-to-end delay with time for the proposed CC-MAC, CCHMAC, HMAC, HSMAC based AOMDV and the existing MAC protocols such as Receiver Initiated Asynchronous Duty Cycle MAC (RI-MAC) [29] and TRAMA

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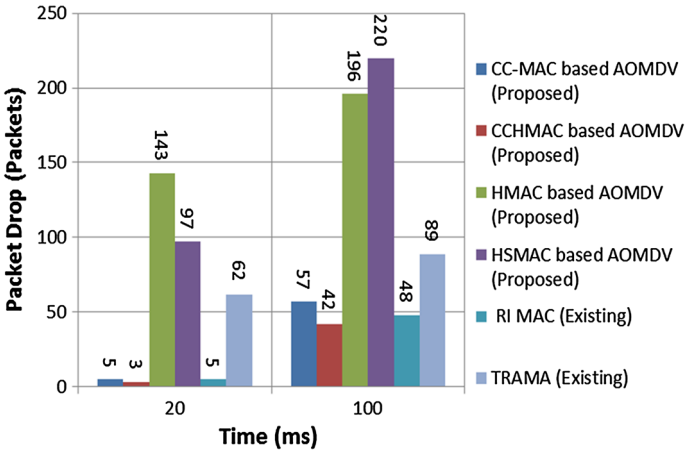


Fig. 17 Time versus packet drop for various protocols

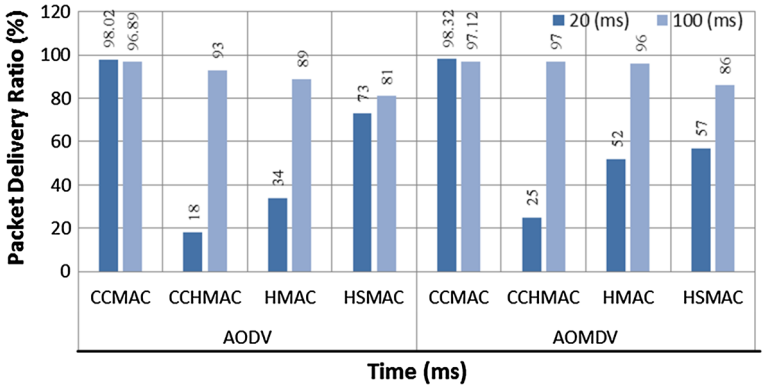


Fig. 18 Time versus packet delivery ratio of CC-MAC, CCHMAC, HMAC and HSMAC based AODV versus CC-MAC, CCHMAC, HMAC and HSMAC based AOMDV

protocols. At 100 ms, the proposed CC-MAC based AOMDV has an end-to-end delay of 1 ms less than the RI-MAC and 6 ms less than the TRAMA protocol. At 100 ms, the proposed CCHMAC based AOMDV has an end-to-end delay of 1.5 ms less than the RI MAC and 6.5 ms less than the TRAMA protocol. At 100 ms, the proposed HMAC based AOMDV has an end-to-end delay of 1.2 ms less than the RI-MAC and 6.2 ms less than the TRAMA protocol. At 100 ms, the proposed HSMAC based AOMDV has an end-to-end delay of 1.3 ms less than the RI-MAC and 6 ms less than the TRAMA protocol.

On an average, CC-MAC based AOMDV has 64 % lesser end-to-end delay value than that of RI-MAC and 93 % lesser end-to-end delay value than that of TRAMA protocol. CCHMAC based AOMDV has 81 % lesser end-to-end delay value than that of RI-MAC and 96 % lesser end-to-end delay value than that of TRAMA protocol. HMAC based AOMDV has 61 % lesser end-to-end delay value than that of RI-MAC and 92 % lesser end-to-end delay value than that of TRAMA protocol. HSMAC based AOMDV has 70 %

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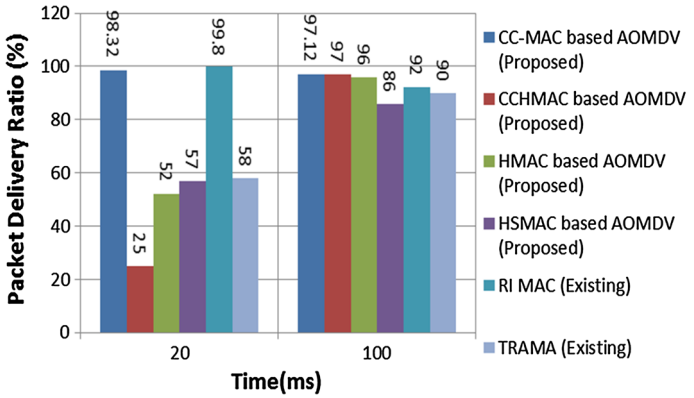


Fig. 19 Time versus packet delivery ratio for various protocols

lesser end-to-end delay value than that of RI-MAC and 94 % lesser end-to-end delay value than that of TRAMA protocol.

5.2 Comparison of Packet Drop with AOMDV Versus AODV

Figure 16 shows the comparison of packet drop with time for the proposed CC-MAC, CCHMAC, HMAC and HSMAC based AODV protocols compared with CC-MAC, CCHMAC, HMAC and HSMAC based AOMDV protocols. At 100 ms, the proposed CC-MAC based AOMDV drops 41packets less than the CC-MAC based AODV as CC-MAC based AOMDV prioritizes the forwarding of filtered data to sink node and routing table entry is easily modified for the maintenance of multiple entries and multiple loop-free paths.

At 100 ms, the proposed CCHMAC based AOMDV drops 46 packets less than the CCHMAC based AODV as CCHMAC based AOMDV provides better QoS and tries to improve the lifetime of the network. At 100 ms, the proposed HMAC based AOMDV drops 116 packets less than the HMAC based AODV as HMAC based AOMDV improves the channel utilization at different network condition and to find node-disjoint routes, each node does not immediately reject duplicate Route Requests (RREQs) to identify node disjoint. At 100 ms, the proposed HSMAC based AOMDV drops 36 packets less than the HSMAC based AODV as HSMAC based AOMDV has fixed listen/sleep schedule and intermediate nodes reply to RREQs.

On an average, CC-MAC based AOMDV has 28 % lesser packet drop value than that of CC-MAC based AODV. CCHMAC based AOMDV has 54 % lesser packet drop value than that of CCHMAC based AODV and HMAC based AOMDV has 37 % lesser packet drop value than that of HMAC based AODV. HSMAC based AOMDV has 14 % packet drop value than that of HSMAC based AODV.

Figure 17 shows the comparison of packet drop with time for the proposed CC-MAC, CCHMAC, HMAC, HSMAC based AOMDV and the existing MAC such as RI-MAC and TRAMA protocols. At 100 ms, the proposed CC-MAC based AOMDV drops 9 packets less than the RI-MAC and 32 packets less than the TRAMA protocol. At 100 ms, the proposed CCHMAC based AOMDV drops 6 packets less than the RI-MAC and 47 packets less than the TRAMA protocol. At 100 ms, the proposed HMAC based AOMDV drops

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148 packets less than the RI-MAC and 107 packets less than the TRAMA protocol. At 100 ms, the proposed HSMAC based AOMDV drops 172 packets less than the RI-MAC and 131 packets less than the TRAMA protocol. On an average, CC-MAC based AOMDV has 42 % lesser packet drop value than that of RI-MAC and 55 % lesser packet drop value than that of TRAMA protocol. CCHMAC based AOMDV has 1.8 % lesser packet drop value than that of RI-MAC and 72 % lesser packet drop value than that of TRAMA protocol. HMAC based AOMDV has 88 % lesser packet drop value than that of RI-MAC and 55 % lesser packet drop value than that of TRAMA protocol. HSMAC based AOMDV has 86 % lesser packet drop value than that of RI-MAC and 50 % lesser packet drop value than that of TRAMA protocol.

5.3 Comparison of Packet Delivery Ratio with AOMDV Versus AODV

Figure 18 shows the comparison of Packet delivery ratio with time for the proposed CC-MAC, CCHMAC, HMAC and HSMAC based AODV protocols compared with CC-MAC, CCHMAC, HMAC and HSMAC based AOMDV protocols. At 100 ms, the proposed CC-MAC based AOMDV has 0.23 % higher packet delivery ratio than the CC-MAC based AODV as CC-MAC based AOMDV is used to find node disjoint and link disjoint routes and the next-hop list, the advertised hop count are reinitialized easily. At 100 ms, the proposed CCHMAC based AOMDV has 4 % higher packet delivery ratio than the CCHMAC based AODV as CCHMAC based AOMDV has two different MAC protocols and the MAC protocols are combined to increase the performance of the network. At 100 ms, the proposed HMAC based AOMDV has 7 % higher packet delivery ratio than the HMAC based AODV as HMAC based AOMDV has slotted frame structure. The slotted frame structure of HMAC protocol improves the packet delivery ratio. At 100 ms, the proposed HSMAC based AOMDV has 5 % higher packet delivery ratio than the HSMAC based AODV as HSMAC based AOMDV has the ability to perform time synchronization and it is suitable for point to point communication.

On an average, CC-MAC based AOMDV has 0.38 % higher packet delivery ratio than that of CC-MAC based AODV. CCHMAC based AOMDV has 8 % higher packet delivery ratio value than that of CCHMAC based AODV and HMAC based AOMDV has 13 % higher packet delivery ratio value than that of HMAC based AODV. HSMAC based AOMDV has 6 % higher packet delivery ratio value than that of HSMAC based AODV.

Figure 19 shows the comparison of Packet Delivery Ratio with time for the proposed CC-MAC, CCHMAC, HMAC, HSMAC based AOMDV and the existing MAC such as RI-MAC and TRAMA protocols. At 100 ms, the proposed CC-MAC based AOMDV has a highest packet delivery ratio of 1.12 % than the RI MAC and a highest packet delivery ratio of 5 % than the TRAMA protocol. At 100 ms, the proposed CCHMAC based AOMDV has 1 % higher packet delivery ratio than the RI-MAC and 5 % higher packet delivery ratio than the TRAMA protocol. At 100 ms, the proposed HMAC based AOMDV has 4 % higher packet delivery ratio than the RI-MAC and 6 % higher packet delivery ratio than the TRAMA protocol. At 100 ms, the proposed HSMAC based AOMDV has 6 % higher packet delivery ratio than the RI-MAC and 4 % higher packet delivery ratio than the TRAMA protocol. On an average, CC-MAC based AOMDV has 0.8 % higher packet delivery ratio value than that of RI-MAC and 21 % higher packet delivery ratio value than that of TRAMA protocol. CCHMAC based AOMDV has 39 % higher packet delivery ratio value than that of RI-MAC and 23 % higher packet delivery ratio value than that of TRAMA protocol. HMAC based AOMDV has 23 % higher packet delivery ratio value than that of RI-MAC and 3 % higher packet delivery ratio value than that of

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TRAMA protocol. HSMAC based AOMDV has 25 % higher packet delivery ratio value than that of RI-MAC and 6 % higher packet delivery ratio value than that of TRAMA protocol.

5.4 Comparison of Throughput with AOMDV Versus AODV

Figure 20 shows the comparison of throughput with time for the proposed CC-MAC, CCHMAC, HMAC and HSMAC based AODV protocols compared with CC-MAC, CCHMAC, HMAC and HSMAC based AOMDV protocols. At 100 ms, the proposed CC-MAC based AOMDV has 635 bytes of higher throughput than the CC-MAC based AODV as CC-MAC based AOMDV has spatial correlation which is exploited on MAC layer and new nodes are deployed in the sensor field to increase the spatial resolution. At 100 ms, the proposed CCHMAC based AOMDV has 3336 bytes value of higher throughput than the CCHMAC based AODV as CCHMAC based AOMDV due to its ability to search for alternate route and higher efficiency. At 100 ms, the proposed HMAC based AOMDV has 807 bytes value of higher throughput than the HMAC based AODV as HMAC based AOMDV because it supports good scalability and time synchronization. At 100 ms, the proposed HSMAC based AOMDV has 10,300 bytes value of higher throughput than the HSMAC based AODV as HSMAC based AOMDV operates on periodic sleep and wake up schedule. It improves the throughput of the network and half, full duplex communication is adaptable.

On an average, CC-MAC based AOMDV has 6 % higher throughput value than that of CC-MAC based AODV. CCHMAC based AOMDV has 24 % higher throughput value than that of CCHMAC based AODV and HMAC based AOMDV has 17 % higher throughput value than that of HMAC based AODV. HSMAC based AOMDV has 23 % higher throughput value than value than that of HSMAC based AODV.

Figure 21 shows the comparison of throughput with time for the proposed CC-MAC, CCHMAC, HMAC, HSMAC based AOMDV and the existing MAC such as RI-MAC and TRAMA protocols. At 100 ms, the proposed CC-MAC based AOMDV has 5052 bytes higher throughput value than that of RI-MAC and 1072 bytes higher throughput value than

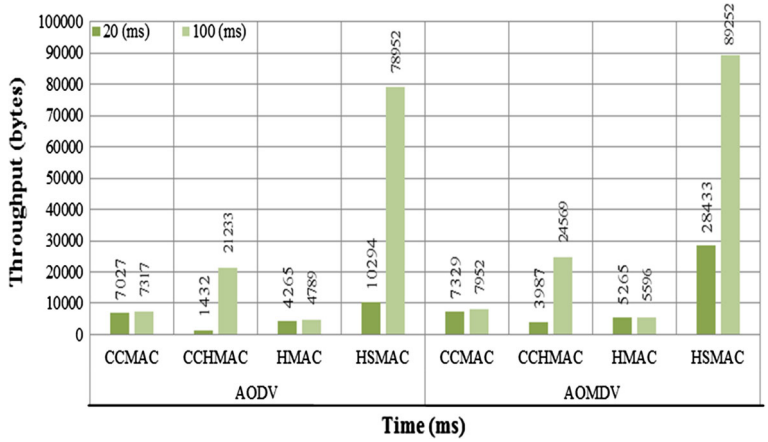


Fig. 20 Time versus throughput of CC-MAC, CCHMAC, HMAC and HSMAC based AODV versus CC-MAC, CCHMAC, HMAC and HSMAC based AOMDV

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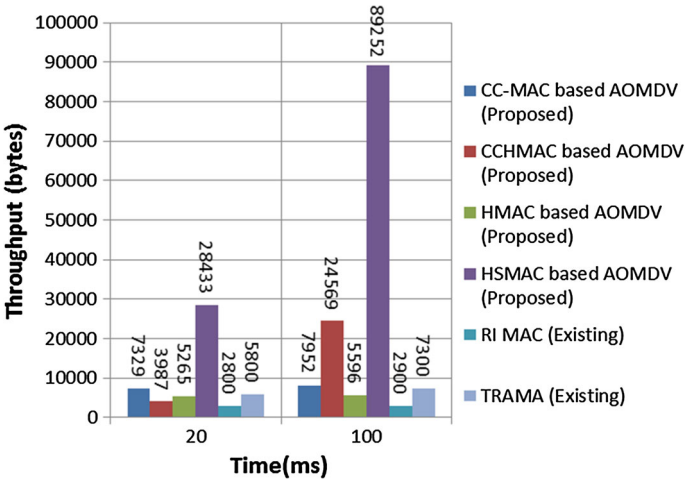


Fig. 21 Time versus throughput for various protocols

that of the TRAMA protocol. At 100 ms, the proposed CCHMAC based AOMDV has 21,669 bytes higher throughput value than that of RI-MAC and 17,269 bytes higher throughput value than that of the TRAMA protocol. At 100 ms, the proposed HMAC based AOMDV has 2696 bytes higher throughput value than that of RI-MAC and 1704 bytes higher throughput value than that of the TRAMA protocol. At 100 ms, the proposed HSMAC based AOMDV has 86,352 bytes higher throughput value than that of RI-MAC and 81,952 bytes higher throughput value than that of the TRAMA protocol.

On an average, CC-MAC based AOMDV has 63 % higher throughput value than that of RI-MAC and 10 % higher throughput value than that of TRAMA protocol. CCHMAC based AOMDV has 78 % higher throughput value than that of RI-MAC and 47 % higher

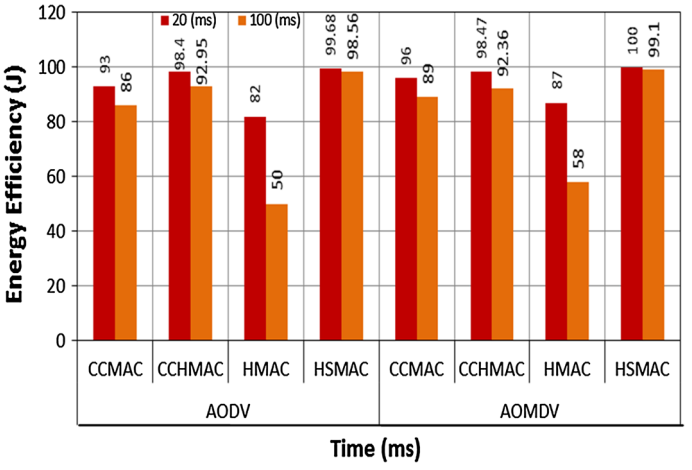


Fig. 22 Time versus energy efficiency of CC-MAC, CCHMAC, HMAC and HSMAC based AODV versus CC-MAC, CCHMAC, HMAC and HSMAC based AOMDV

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throughput value than that of TRAMA protocol. HMAC based AOMDV has 47 % higher throughput value than that of RI-MAC and 22 % higher throughput value than that of TRAMA protocol. HSMAC based AOMDV has 95 % higher throughput value than that of RI-MAC and 89 % higher packet delivery ratio value than that of TRAMA protocol.

5.5 Comparison of Energy Efficiency with AOMDV Versus AODV

Figure 22 shows the comparison of energy efficiency with time for the proposed CC-MAC, CCHMAC, HMAC and HSMAC based AODV protocols compared with CC-MAC, CCHMAC, HMAC and HSMAC based AOMDV protocols.

The energy spent in transmission of a single bit is given by Eq. 7

$$e_{tx}(d) = e_{t_l} + e_{d_l} * d^n. \tag{7}$$

The total energy dissipated for transmitting a K-bit packet is given by Eq. 8,

$$E_{tx}(K, d) = (e_{t_l} + e_{d_l} * d) * K \tag{8}$$

e_{t_l} is power dissipated for transmitting 1-bit data and e_{d_l} is energy for transmission over a distance d. K represents total number of bits.

At 100 ms, the proposed CC-MAC based AOMDV has 3 J higher energy efficiency than that of CC-MAC based AODV as CC-MAC based AOMDV adapts iterative node selection procedure to get better values of energy efficiency. At 100 ms, the proposed CCHMAC based AOMDV has 1.7 J higher energy efficiency than that of CCHMAC based AODV as CCHMAC based AOMDV due to its ability to search for alternate route and higher efficiency. At 100 ms, the proposed HMAC based AOMDV has 8 J higher energy efficiency than that of HMAC based AODV as HMAC based AOMDV because it has slotted frame structure that helps to improve energy efficiency of the network. At 100 ms, the proposed HSMAC based AOMDV has 0.54 J higher energy efficiency than that of HSMAC based AODV. In HSMAC based AOMDV, each node alternates between a fixed length listen period and fixed length sleep period therefore energy wastage is avoided. On an average, CC-MAC based AOMDV has 1.8 % higher energy efficiency than that of CC-MAC based AODV. CCHMAC based AOMDV has 0.43 % higher energy efficiency than

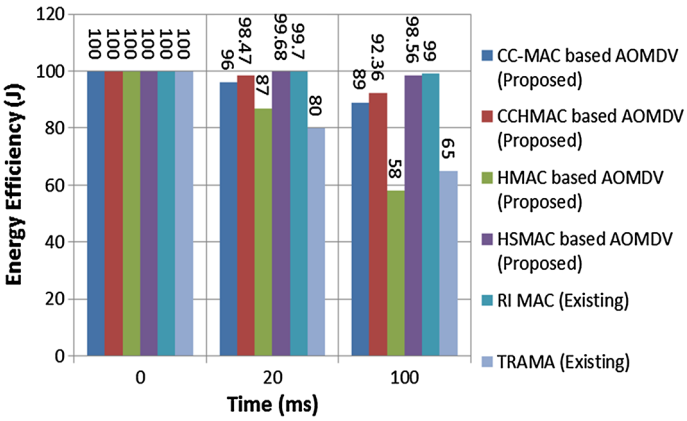


Fig. 23 Time versus energy efficiency for various protocols

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that of CCHMAC based AODV and HMAC based AOMDV has 9 % higher energy efficiency than that of HMAC based AODV. HSMAC based AOMDV has 0.39 % higher energy efficiency than that of HSMAC based AODV.

Figure 23 shows the comparison of energy efficiency with time for the proposed CC-MAC, CCHMAC, HMAC, HSMAC based AOMDV and the existing MAC such as RI-MAC and TRAMA protocols. At 100 ms, the proposed CC-MAC based AOMDV has 10 J higher energy efficiency than that of RI-MAC and 24 J higher energy efficiency than that of the TRAMA protocol. At 100 ms, the proposed CCHMAC based AOMDV has 6.6 J higher energy efficiency than that of RI-MAC and 27 J higher energy efficiency than that of the TRAMA protocol. At 100 ms, the proposed HMAC based AOMDV has 41 J higher energy efficiency than that of RI-MAC and 7 J higher energy efficiency than that of the TRAMA protocol. At 100 ms, the proposed HSMAC based AOMDV has 0.44 J higher energy efficiency than that of RI-MAC and 33.6 J higher energy efficiency than that of the TRAMA protocol.

On an average, CC-MAC based AOMDV has 6 % higher energy efficiency than that of RI-MAC and 19 % higher energy efficiency than that of TRAMA protocol. CCHMAC based AOMDV has 3 % higher energy efficiency than that of RI-MAC and 21 % higher energy efficiency than that of TRAMA protocol. HMAC based AOMDV has 20 % higher energy efficiency than that of RI-MAC and 4 % higher energy efficiency than that of TRAMA protocol. HSMAC based AOMDV has 0.2 % higher energy efficiency than that of RI-MAC and 24 % higher energy efficiency than that of TRAMA protocol

Figure 24 shows the comparison of energy consumption with time for the proposed CC-MAC, CCHMAC, HMAC, HSMAC based AOMDV and the existing MAC such as RI-MAC and TRAMA protocols. It is observed that HSMAC based AOMDV for WSN shows better result than the other existing algorithms. From the above Figs. 14–24, CC-MAC, CCHMAC, HMAC, HSMAC based AOMDV produces better value of throughput than CC-MAC, CCHMAC, HMAC, HSMAC based AODV protocol. Hence for the comparison with existing protocols, CC-MAC, CCHMAC, HMAC, HSMAC based AOMDV are taken. From the analysis, HSMAC based AOMDV achieves better value of energy efficiency when compared with the other protocols.

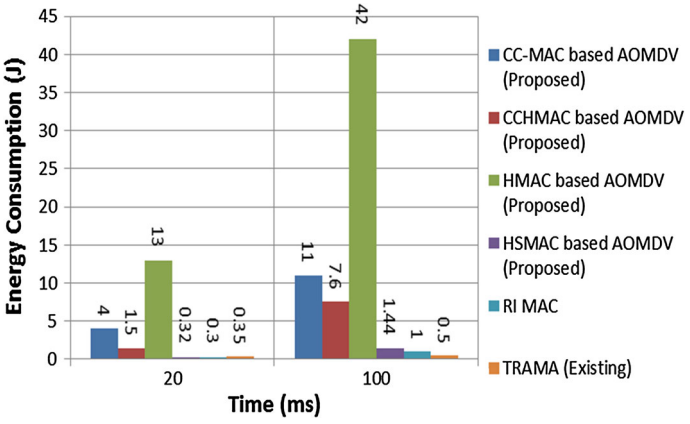


Fig. 24 Time versus energy consumption for various protocols

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The proposed work is compared with the existing algorithms based on CC-MAC and sensor MAC protocols [3]. It is found that the proposed HSMAC based AOMDV protocol achieves good results compared with the existing methods in terms of throughput, end-to-end delay, packet drop rate, energy efficiency, energy consumption as well as packet delivery ratio. Because HSMAC based AOMDV has less inter nodal co-ordination overhead and better level of scaling compared to AODV protocol.

6 Conclusion and Future Work

In this paper, spatial correlation based cross layer approach with routing in WSNs is proposed. The performance of the four proposed MAC protocols with routing is compared with the existing MAC protocols such as RI-MAC and TRAMA. From the results it has been observed that the proposed algorithm performs better with high energy efficiency, higher throughput, higher packet delivery ratio, lesser end-to-end delay and lesser packet drop than that of the existing algorithms. HSMAC based AOMDV has 24 % higher energy efficiency than that of TRAMA protocol. HMAC based AOMDV has 20 % higher energy efficiency than that of RI-MAC protocol. Compared to all the MAC protocols, Hybrid medium access protocols such as HMAC and HSMAC based AOMDV produces best result towards energy efficiency. Clustering operation is not considered in the Spatial Correlation based cross layer approach with routing model. In future, Clustering methods and hierarchical routing protocols can also be considered to analyze the network performance.

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