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A Medium Access Control Protocol for Multi-Channel Wireless Sensor Networks

Siddhartha Adhyapok[1], Bhaskar Bhuyan[1], Anand Sharma[2], Hiren Kumar Deva Sarma[3]*

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Abstract: This study proposes a medium access control (MAC) mechanism for multi-channel wireless sensor networks. The suggested protocol is based on clustering. The sensor field under consideration is clustered virtually. In order to choose the cluster head nodes, Analytical Hierarchy Process (AHP) based method is used. AHP is an efficient tool for decision-making process. Each cluster in the network has a random number of fixed and mobile sensor nodes. Moreover, the sensor nodes support multi-channel communications. Data communication takes place in two different phases. Data is forwarded from the source node to the cluster head node, which then either directly or via many hops passes it to the sink. In the proposed method, the channel allocations happen in an energy efficient manner. The proposed protocol has been evaluated for its performance through Matlab 7.1. The effectiveness of the suggested protocol has been assessed and contrasted with that of RTMAC (Receiver-Initiated MAC Protocol) and MCPS (Multi-Channel Preamble Sampling). In comparison to these two protocols, the suggested protocol performs improved in terms of energy efficiency, throughput, and end-to-end delay. The work's future scope is described.

Keywords: *Analytical Hierarchy Process, Wireless Sensor Networks, Cluster, Energy Efficient, Multi-channel Wireless Sensor Networks, Mobility.*

1. Introduction

There has been tremendous progress in hardware technologies as well as in communication technologies in the last decade. Commercially available sensor nodes with multi-channel communication capabilities are currently available. Consequently, there has been a propensity for these multichannel sensor nodes to be adopted in the context of typical wireless sensor networks (WSN). Multi-channel Wireless Sensor Networks (MWSN) perform noticeably better than single-channel Wireless Sensor Networks (SWSN). WSNs in which sensor node hardware support multiple frequencies for communication, are considered as multi-channel WSNs [1]. In a MWSN setup, the nodes have multiple options for data communication as they are equipped with multiple channels [2]. Consequently, the nodes are able to select their preferred transmission channels. It's crucial to recollect that MWSNs consume more energy than WSNs with a single channel [3]. In general, for low traffic condition, single channel WSN performs well specially while energy efficiency is considered, but for huge traffic load, it is difficult for single channel WSN to handle the situations [4]. For huge traffic, MWSN performs well in comparison to single channel WSN [5]. Although a large number of WSN protocols have previously been designed, they are not compatible with the MWSN architecture. To fully harness the possible of the MWSN system, appropriate protocols and algorithms need to be developed at each tier, from the physical to the application layer. Again, the effective functioning of a MWSN configuration depends on the routing and medium access control protocols. Thus, developing efficient protocols for different purposes involved in various layers of the protocol stack is an open research area. Specially, when quality of services aspects is considered, such developments of efficient protocols are challenging tasks. MWSN has a wide variety of applications starting from Industrial Internet of Things (IIoT) to precision agriculture. In many application areas of traditional WSN, there is a tendency to replace the traditional WSN by MWSN. This is so, as in early days, there were limitations in hardware as well as in software sides. However, these days, hardware technologies have advanced significantly, and sensor nodes in specific are more supportive of multi-channel communications and more effective in terms of communication and energy consumption [6]. Overall, WSN applications are seen in fields like military, construction, healthcare, agriculture, infrastructure monitoring etc. [7] [8].

Problem statement:

Channel allocation in MWSN is a challenging task. Moreover, the application specific nature of WSN makes this task even more challenging. For example, real-time applications of WSN or MWSN will demand delivery of data within specified deadlines. Moreover, energy efficiency is of utmost importance. At the same time, the

[1] Department of IT, Sikkim Manipal Institute of Technology, Majitar, Sikkim, India, 737136
[2] Department of CSE, Mody University, Lakshmangarh, Rajasthan, India, 332311
[3] Department of IT, Gauhati University, Guwahati, Assam, India, 781014
** Corresponding Author Email: hirenkdsarma@gmail.com*

sensor nodes are energy constrained. In spite of these, overall performance of the sensor network has to be enhanced. The problem undertaken in this paper may be stated formally as: *to develop a medium access control (MAC) protocol for MWSN with energy efficiency as the primary design objective*. While designing, Analytical Hierarchy Process (AHP) may be exploited for making optimized decisions regarding channel selection and subsequent allocation.

Background:

MCPS (Multi-Channel Preamble Sampling) [9][10] and RITMC (Receiver-Initiated MAC Protocol) [11][12] are two well known MAC protocols that are developed and available for MWSN. Again DBCA (distance-based channel allocation), is the mechanism used by the MCPS. Utilizing such an assignment approach, perhaps MCPS is the first multi-channel MAC protocol. Energy usage is decreased with the DBCA technology. Another energy-efficient MAC approach is the RITMC protocol. However, none of these protocols take care of the mobility aspect involved in the ordinary sensor nodes as well as the sink or the base station. Moreover, there isn't much literature out there that takes sensor node mobility into account.

In this paper, a MAC protocol for MWSN has been proposed. This technique takes into account the sensor nodes' movement while treating the sink as stationary. The proposed approach exploits the principles of AHP. Since there will be multiple channels accessible in the MWSN configuration, the suggested protocol satisfies the requirements of the Analytical Hierarchy Process (AHP) application, and also justifies exploring AHP for decision making with respect to the selection of channels. The proposed protocol is named as AC-MAC (Analytical hierarchy process based Clustered Medium Access Control) protocol. As the title suggests the protocol is cluster based. The sensor ground is virtually clustered into multiple clusters after deployments of the sensor nodes. This clustering of the sensor field may be achieved by using standard clustering technique which is already available in literature [13][14][15][16][17][18]. The work of choosing a channel starts after the clusters are created and the corresponding cluster head nodes are chosen. As there are multiple channels available with each node including the cluster head nodes, identifying a proper channel for communication between two entities is an important task as well as a challenging task. Nonetheless, the scalability and energy efficiency of cluster-based protocols and techniques have already been proven. There are few cluster-based protocols available for multi-channel WSNs and are reported in [19][20]. In case of cluster-based approach, the transmissions are always hierarchical. The appropriate cluster head (CH) node receives the data from the standard sensor nodes, and then it either transmits the data directly to the sink or through a multi-hop protocol. Multi-hop protocol involves a few more CH nodes as intermediate nodes along the route toward the sink. Overall, this technique uses less energy. Usually, the cluster head node accepts data from its cluster members and then sends data to the sink. Therefore, all intra-cluster transmission between organized cluster member (CM) nodes and the associated CH node in a MWSN arrangement must utilize the appropriate communication channels. Additionally, the appropriate channels need to be identified for the complete multi-hop communication, which starts with a confident CH node and ends with the base station. In different scenarios, the communication channel (s) between any two entities involved in the entire route toward the sink may be either the same one, or even multiple. It is important to mention that the terms sink and base station are used interchangeably.

Preliminary:

As it has already been mentioned, in the proposed AC-MAC protocol, the cluster formation can be achieved through any standard clustering protocol available in literature [13][14][15][16][17][18]. Moreover the cluster head nodes may be selected using a novel approach which is AHP based [31]. Analytical Hierarchy Process (AHP) is a very powerful method for figuring the optimal decisions [21][22]. The principles of AHP have been exploited in this proposed channel allocation mechanism. Using AHP, the proposed AC-MAC protocol can dynamically allocate channels to the nodes for data transmission. This means that the channel selection is done at the time of data transmission. Availability and use of multiple channels enhance the efficiency of AC-MAC protocol. It is assumed that different channels have different colours to identify them uniquely in the entire system [23]. After channel selection, data communication started. While the CH node manages long-distance transmission with the base station, the cluster members (CM) use the assigned channel to send data toward the appropriate CH node. Different time slots are allotted to different CH nodes in order to facilitate data transfer. The CH nodes broadcast data on a regular basis.

The rest of the document is organized as follows: Section 2 outlines related works followed by the section 3 in which the proposed protocol is detailed. Section 4 presents simulation results and analysis of the results and section 5 concludes the work.

2. RELATED WORKS

There are a number of MAC protocols developed for multi-channel WSN, to improve the network efficiency. Some of these protocols were first created for WSNs with a single channel. Toward the end, MAC protocols that allow access to several frequencies were also developed for multi-channel based WSN. On the other hand, there are flaws with the MAC protocol's design, like missing receivers and hidden terminals. The channel allocation technique of MAC protocols can be categorized into three groups: fixed channel allocation, semi-dynamic channel allocation, and dynamic channel allocation. The following discusses a few of the most current MAC protocols created especially for MWSN.

Hanan Alahmadi (2018) proposed a MAC protocol named as Multi-Channel Preamble Sampling (MCPS)[9][10]. This protocol was developed for multichannel WSN that uses a preamble sample approach. This MAC protocol uses CSMA/CA technique to operate at minimal power. MCPS makes use of every non-overlapping channel on the IEEE 802.15.4 physical layer. Preamble sampling is a technique used by MCPS to awaken a designated receiver in a shared control channel. Data transport takes place over a dedicated channel. Sensor nodes can dynamically adjust the transmission power at which they send data that is regularly created or stored as preamble. MCPS selects the optimal data channel by varying the transmission power for each pair of communication nodes. The simulation's outcomes show how successful the MCPS protocol is in terms of throughput and end-to-end latency.

Renato F (2018) proposed a MAC protocol named as Receiver-Initiated MAC Protocol (RITMC) [11][12]. The proposed one is an asynchronous MAC protocol planned for multi-channel WSN. It is based on receiver-initialization. RITMC protocol is based on A-MAC protocol [24], but the difference is that RITMC does not use hardware-based ACK. One addition in the RITMC is the efficient diagnostics service which is not available in A-MAC protocol. By using initial acknowledgement mechanism (that is used to lower Idle Listening), RITMC protocol consumes minimum energy to operate. The protocol is efficient as it uses less communication steps due to an optimized approach. It uses an efficient channel selection algorithm for communication. The outcome of the experiment demonstrates the efficiency of the RITMC protocol with regard to latency, energy efficiency, and network throughput.

Hao, M., (2020) proposed a MAC protocol named as Multi-Channel Spreading Factor based MAC (MSF-MAC) [25]. This efficient MAC protocol was developed for wireless mesh networks with several channels. The protocol uses hybrid CSMA along with scheduled access to distribute channels. It allows for simultaneous data transmission from several users. A clustering model is used by MFS-MAC to accomplish energy efficiency. This method combines the spread-spectrum channel allocation algorithm with the polling super-frame structure methodology. The simulation's findings show that the MFS-MAC protocol performs well in terms of throughput, overhead, and delay.

Rambabu, C (2020) proposed a MAC protocol titled as Multipath Cluster-Based Hybrid MAC (MPCB-HM) [26]. This protocol is an example of hybrid approach combining CSMA/CA, TDMA and FDMA. Since it uses multi-channel, high data rate channel can be shared among various channels. The MPCB-HM protocol facilitates communication both within and between clusters. Moreover, this protocol uses one collision-free technique. The protocol can shift control from TDMA to CDMA and vice-versa. The protocol permits network scalability as it uses cluster-based topology. The simulation's outcome demonstrates the MPCB-HM protocol's efficiency with regard to overall network performance, scalability, and energy efficiency.

Roy, A. (2021) proposed a MAC protocol titled as Multichannel Ordered Contention MAC (MOC-MAC) [27]. A MAC protocol for multi-channel WSN that is intended for deep underwater monitoring was presented in this study. Its foundation is the OCMAC (Ordered Contention MAC) protocol [28], which is a single channel protocol designed to increase the network throughput. MOC-MAC is a synchronous reservation-based multi-channel MAC protocol designed to reduce collisions in high-traffic networks. It exploits advantage of the scheduling mechanism found in the OCMAC protocol to lessen collisions. Nodes that receive RTS frames from several senders are scheduled to reserve a channel in a way that reduces the handshake time. Senders begin data transmission in the sequence specified in the transmission schedule without encountering any collisions after properly reserving the channel. MOC-MAC primarily uses 2 channels for data transmission and channel reserve. Simulation outcomes display that the MOC-MAC protocol performs improved in terms of network throughput.

Alzahrani, E (2021) proposed a MAC protocol named as Quorum-based Multi-channel MAC (QMMAC) [29]. This MAC protocol has been designed for multi-channel based WSNs. It is based on quorum concept and thus titled as Quorum based Multi-channel MAC (QMMAC). It used sleep and weak up mechanism, in order to incur low power consumption. Simultaneous communications are possible due to the availability of multiple channels. Weak up scheduling is maintained for each node and is forwarded to the nodes when communication is required. At the same time, communicating node becomes ready and its forwarding nodes also wake up. It will avoid collision and network overhearing. QMMAC uses quorum technique, which improve network throughput. For channel allocation, quorum concept is used, which share the data channel to avoid additional packet exchange. It minimizes the delay and collision between the nodes. Simulation results show that QMMAC has good throughput, energy efficiency, and end-to-end latency.

Wei, Y (2023) proposed a MAC protocol titled as Graph Coloring-based Multi-channel MAC (GCMAC) [30] protocol. A MAC protocol based on coloring graph theory is proposed in this study. The Graph Coloring-based Multichannel MAC (GCMAC) protocol has specifically been created for dispersed underwater wireless sensor networks. The lengthy propagation delay, hidden terminal problem etc were targeted to be resolved through this protocol. There are three phases in this protocol. Phases one and two are channel negotiation and channel selection, respectively. And the phase three is data transmission. Graph coloring theory is the basis for channel allocation and negotiation for choosing the best channel for data transmission. This procedure helps in efficient channel usage and it also avoids collision. The outcomes of the simulation show how successful the GCMAC protocol is in terms of energy effectiveness and network performance.

A comparison of the above mentioned MAC protocols is presented in Table 1.

Table1: Summary of various MAC protocols

Protocols	Quality of services parameters					
	Energy efficiency	End-to-end delay	Throughput	Packet delivery ratio	Network lifetime	Scalability
MCPS [10]	-	Yes	Yes	-	-	-
RITMC [12]	Yes	Yes	-	Yes	-	-
MSF-MAC [18]	-	Yes	Yes	-	-	-
MPCB-HM [19]	Yes	-	-	-	-	Yes
MOC-MAC [20]	-	-	Yes	-	Yes	-
QMMAC [22]	Yes	Yes	Yes	-	-	-
GCMAC [23]	Yes	-	Yes	-	-	-

It is observed that the problem of node and base station mobility, either in conjunction or independently, is not considered by any of the previously stated protocols. Furthermore, there is a need to develop MAC protocols for MWSN that can ensure quality of services, as a whole.

3. PROPOSED WORK

In this section, a medium access control approach titled as AC-MAC (Analytical hierarchy based Clustered MAC) protocol is proposed. The complete protocol is defined in terms of several phases such as network deployment, clustering and cluster head selection, and channel allocation and data transmission.

In general, the network operations advance through various phases as mentioned below:

Phase 1: Network deployment

Phase 2: Clustering and Cluster head selection

Phase 3: Channel allocation

Phase 4: Data transmission

These phases are detailed in this sub-section.

3.1. Phase 1 (Network deployment):

The multichannel wireless sensor network is set up at this phase. The placement of the sensor nodes is haphazard. Nodes have many channels installed and are set up to transfer with these channels. There are mobile nodes and stationary nodes among the nodes. Depending on the kind of application, mobilizer units may be attached to the mobile sensor nodes or they may be attached to other mobile objects. A maximum speed of 2 to 3 meters per second is anticipated for the node. The sink is considered to be situated outside of the sensor field. An ID gives each node a distinct identity. The network is self-starting and self-organizing by nature.

3.2 Phase 2 (Clustering and Cluster head selection):

The entire sensor field is clustered using a standard node clustering technique once the nodes are deployed. The cluster generation algorithm is not intended to be addressed by this study. It has been assumed that several sensor nodes are virtually clustered together to form clusters based on specific variables like residual energy, position, etc., depending on the type of application. This study focuses primarily on the cluster head node selection procedure after the clusters are formed.

In paper [31], a node clustering and cluster head selection methodology for MWSN has been proposed by this research group. Briefly, cluster formation mainly depends on geographical location of each node and ideal channel. Static node always stays in the same cluster. Mobile node changes their cluster depending on speed and direction. Geographically nearest nodes belong to the same cluster. It assumed that the same channels are available inside one cluster; however this may not be possible all the time. Cluster head is responsible for communication of data to the base station. For each cluster, a CH node is selected which ideally needs to be highly capable in terms of residual energy, and other parameters such as connectivity with other nodes inside the cluster, channel availability etc. Details description of cluster head selection is available in [31].

3.3 Phase 3 (Channel allocation):

The proposed AC-MAC protocol supports dynamic channel allocation. This is achieved through the use of AHP. Various steps involved in channel allocation are described below:

Step 1: check channels from first to the last; if any one of the channels is idle, allocate it;

Step 2: if the all channels are busy, go to the step 3;

Step 3: find the most appropriate channel using AHP;

Step 4: allocate the most appropriate channel identified in step 3.

Various parameters used here in channel allocation are: Number of channels, Time slot, Channel frequency, Channel sense, Channel same-ability. These parameters are explained in the following sections.

In single channel WSN setup, only one channel is available for communication, and there is no option for data transmission. All the nodes must use that particular channel only. In multi-channel WSN setup, there are numbers of channels present for data communication. For this reason, the nodes have choices to select channels. If the traffic volume in the network is low, then there may be some chances of finding few idle channels. But for heavy traffic condition, even availability of multiple channels in the system may not be sufficient for data transmission. Under such condition, it might be difficult to find an idle channel. Therefore, finding out the most appropriate channel under heavy traffic condition is again a challenging task; and there is scope to apply principles of AHP to find the most appropriate channel.

In the following section, the process of applying AHP for channel selection is detailed.

Here, N represents number of available channels. It is decided at the time of network deployment. In this work, N is considered to be 8.

For heavy traffic condition, there may be no any idle channel available for data transmission, at a given time. Thus, a channel may have to be shared by more than one node. Time division multiple access (TDMA) is a technique for channel sharing where each node is assigned a certain time slot to access the channel. Now, to determine these time slots for different nodes in an optimal manner is not easy task. If time slot is small, then large amount of data may not be transmitted during one slot. If time slot is large then for small amount of data, unused slots may be produced. For this reason, the duration of time slots can be kept fixed. It is more acceptable, if the duration of such time slots can be decided at the time of transmission, dynamically. Finally, goal is to assign suitable time slot to a particular node.

Thus, when equal time slots are allocated to different nodes, equation (1) represents the scenario.

$$T=N.T_i \qquad (1)$$

Here, T= Total time duration of the entire session,

Ti= Time slot allocated to node i,

N= Total number of nodes.

For multi-channel environment, there are more than one frequency band which are available for communication. To communicate, nodes use a specific frequency band. Number of channels defines the total frequency bands present in the system. Number of channels is pre-defined, and thus fixed. As mentioned earlier, for low traffic, single frequency may be sufficient. For heavy traffic it may not be sufficient to find an idle channel. Now, in AHP based method, some weights are assigned on available channel frequencies for appropriate channel allocation. Frequency F is expressed in equation (2).

To assign a particular frequency to a node:

$$F=\sum F_i \qquad (2)$$

F= total number of frequencies available,

Fi= ith frequency assigned to a node, where $1<i<F$.

Channel sensing is an important task for dynamic allocation of a channel. Before transmission, a node must sense the channel; if channel is idle, then the node can communicate data. If the channel is full, then the node can sense another channel depending on the MAC protocol. AHP works on various weighted parameters that affect the channel allocation process. In the proposed method, some weights are given to channel sense in the channel allocation process.

In case of multi-channel network, nodes have multiple options for data transmission with respect to channel selection in the entire route. If transmission is done through same channel from sender to the receiver, then network overhead is reduced. For this reason, we have to check the availability of the same channel from beginning till end of the route. In the proposed method of channel allocation, a priority value is allocated a channel if the same channel is free in the entire route for a particular data transmission session. If the channel is busy in some portion of the route, then channel switching is needed. Channel switching is costly and in order to avoid channel switching, it is always preferred to select the channel which is free from sender to receiver. For this reason, channel same-ability has the height priority among all the AHP criteria. Figure 1 depicts the hierarchical organization of different criteria used in the channel allocation process as per the AHP principles.

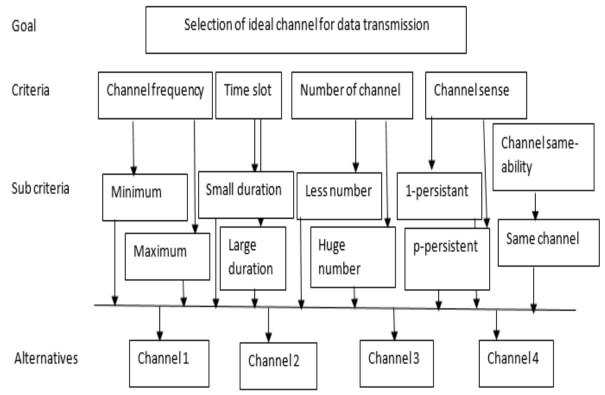

Figure 1 Hierarchical view of the channel allocation mechanism

The scale of importance as per the AHP specification is presented in Table 2.

Table 2: The scale of relative importance

Weights	Description
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extremely importance value

Here, 1/3 1/5 1/7 1/9 used for inverse calculation. And, 2 4 6 8 are intermediate values.

An appropriate channel can be assigned to a node once all the criteria have been examined. Achieving the highest priority channel assignment is the ultimate aim. The matrix Zij is first formulated in order to compute the priority. The relative weight of each level's criteria is represented by the variable "Zij." The scale of importance is already presented in Table 2; and table 3 displays the matrix Z.

Table 3: Matrix Z=(Zij), representation

	Number of channel	Time slot	Channel frequency	Channel sense	Channel same-ability
Number of Channel	1	Znt	Znf	Zns	Znsa
Time slot	Ztn	1	Ztf	Zts	Ztsa
Channel frequency	Zfn	Zft	1	Zfs	Zfsa
Channel sense	Zsn	Zst	Zsf	1	Zssa
Channel same-ability	Zsan	Zsat	Zsaf	Zsas	1

Explanation of the matrix Z i,j: For every decision criterion in the AHP-based method, Z=(Zij), n×n, (which is the comparison matrix) is computed, where n is the entire number of criteria at each level. Z i, j is a representation of the comparative relevance of criteria i to j. Here, Z i,j = 1/ Z i,j denotes the mutual value of criteria j in relation to criteria i; Z i,j = 1 specifies that i=j; if Z i,j = 1, then it specifies that criteria i are relevant to criteria j. In this instance, the five criteria as mentioned below: channel count, time slot, frequency, sense, and same-ability, are met. As seen in the aforementioned matrix (table 3), Zst, for instance, indicates the proportional importance of channel sense to time slot metric and so forth.

Next, the Eigen vector is computed in accordance with the AHP principle; priorities are also computed; and lastly, the factors listed below are ascertained [32].

Consistency index is represented as shown in the equation (3).

Consistency index (CI):

$$CI = \frac{\lambda max - n}{n-1} \qquad (3)$$

λmax= maximum Eigen value of matrix $Z_{i,j}$;

n= number of criteria.

Random consistency index (RI): Table 4 shall be utilized to extract the value of RI, which is associated with the matrix's dimension. It should be mentioned that a consistency ratio of less than 0.10 indicates that the comparison's findings are legitimate.

Table 4: The value of Random Consistency Index, Source: [33]

Dimension	RI
1	0
2	0
3	0.5799
4	0.8921
5	1.1159
6	1.2358
7	1.3322

8	1.3952
9	1.4537
10	1.4882

Finally, to authenticate the results of the AHP, the consistency ratio (CR) is considered using the formula:

$$CR = CI/RI \quad (4)$$

To determine the ideal set of parameters, a thorough investigation has been conducted using a variety of parameter configurations. A comparative matrix Zi,j is used to assess the effects of the various parameters (such as channel count, time slot, frequency, sense, and same-ability) and is shown in Table 3. After a thorough analysis, the remaining combination demonstrates the relative significance of the coefficients.

Table 5: Weight value assumption based on table 2

	Number of channel	Time-slot	Channel frequency	Channel sense	Channel same-ablity
Number of channel	1	1/5	4	5	¼
Time-slot	5	1	1/6	¼	1/6
Channel frequency	¼	6	1	6	4
Channel sense	1/5	4	1/6	1	1/7
Channel same-ablity	4	6	¼	7	1

We use four channels (channel 1, channel 2, channel 3, and channel 4), as an example. We calculated and discovered that channel 1 is the most important. The aggregate weights of the four channels are shown in Figure 4.

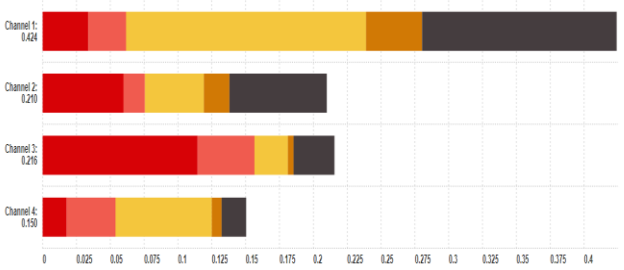

Figure 4: Overall weights of the four channels

The relative ranks of the criteria are shown in Table 6. Based on the assumptions presented in Table 5, it is evident that while channel sense is the least significant of the five decision criteria, channel frequency metric has a greater priority and influences channel selection decisions. Table 6 displays all other criteria along with their corresponding priority levels.

Table 6: Relative ranking of the criteria

Criteria	Value	Importance
Number of channels	0.226	The third important criteria
Time slot	0.122	The fourth important criteria
Channel frequency	0.317	The most important criteria
Channel sense	0.072	The least important criteria
Channel same-ability	0.264	The second important criteria

Sensitivity analysis:

Finally, a sensitivity analysis is conducted to demonstrate how changing the various process parameters affects the selection of the appropriate channel. The process's current values are initially shown. Figure 2 shows how important each option is right now when all the model's requirements are taken into account. Figure 2 shows that the maximum value is in line with the channel frequency. Furthermore, Figure 2 illustrates the weights assigned to every one of the five primary criteria— number of channels, time slot, channel frequency, channel sense, and channel same-ability—in relation to the four possible channels, namely channels 1, 2, 3, and 4.

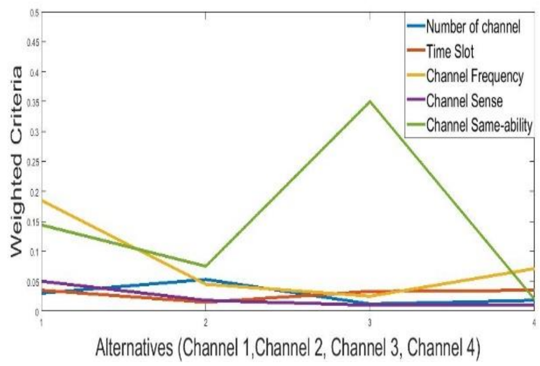

Figure 2: Sensitivity graph - the weighted criteria with respect to select the proper channel

Figure 3 represents the overall process of using AHP in channel selection. There are two primary factors to start the process. One is selection criteria, and the other is importance scale. Criteria are explained in figure 3 and importance scale is explained in table 2. Calculations are explained through the matrix Zij as mentioned above (table 4). Depending on the CR value, channel is selected for data transmission. In [31] a similar approach was adopted for selection of cluster head nodes exploiting the principles of AHP.

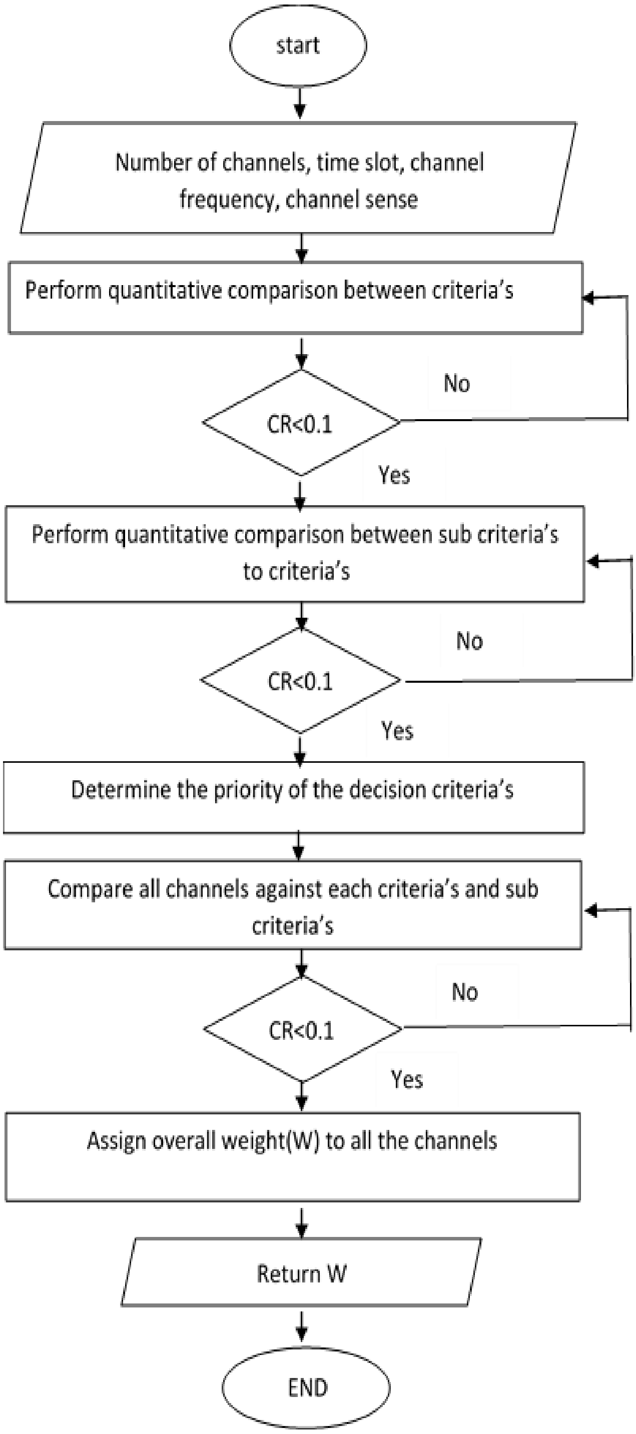

Figure 3 Use of AHP to compute the weights for channel allocation process

4. SIMULATION RESULTS

Matlab 7.1 has been used to do extensive simulations of the proposed AC-MAC protocol. AHP mechanism has been incorporated into the simulation setup to compute the weights of the channels and surrounding nodes. Every node will have a CR value, regardless of its mobility value (mobile or static). Several types of simulation parameters are included in Table 7.

Table 7: Simulation parameters considered

Parameters	Value
Number of channels	8
Number of nodes	100 (75static node 25 mobile node) with one static sink (or base station)
Node velocity	2-5 meter/second
Initial energy of each sensor nodes	Eo= 10 Joule
Radio range	50 meters
Packet queue size	10 packets
Packet size	4000 bits
Simulation surface	100 X 100 (in meters)
Topology	Random
Packet generation rate	10 packets per second
Number of reading repetitions	10

The proposed AC-MAC protocol has been simulated and performance comparison has also been carried out. In order to compare the performances, the MCPS [9][10] and RITMC [11][12] protocols are considered. These two protocols have been discussed in section 2. Among the several QoS (Quality of Services) factors taken into account for the comparative analysis are throughput, end-to-end latency, and energy efficiency.

Energy efficiency: Each node contains a battery that serves as an independent energy source. Static nodes consume less energy than mobile ones do. The mobile node's ability to get closer to the base station is one of its advantages. Each node has a same initial energy level. A certain quantity of the battery power is used once the first iteration is finished. The initial energy for the second round is then each node's remaining energy at the end of the previous round.

Figure 4 shows total energy consumed after different numbers of iterations (1 to 10) under the influences of different MAC protocols. This total energy is expended in the system due to reception, and transmission of data packets, control overheads, and also idle listening. The suggested procedure is shown to use the least amount of energy when compared to the two other comparable protocols, RITMC and MCPS. The minimum channel switching caused by the suggested protocol is one of the causes of this. Furthermore, slight channel switching has been guaranteed by the AHP-based channel selection. The readings (in figure 4) were taken without assigning any predetermined priority to any of the parameters. The proposed protocol consumes lesser energy in comparison to the benchmark protocols. This is again because of better allocation of channels under the influence of the proposed protocol.

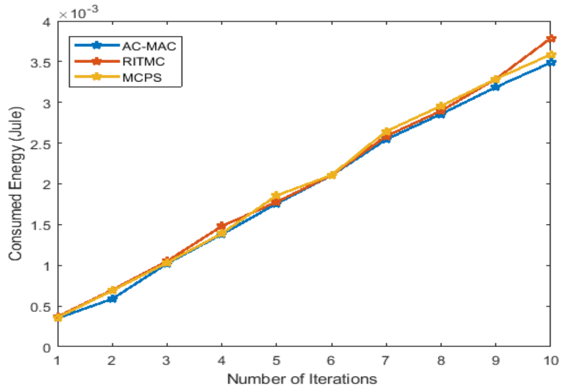

Figure 4 Energy consumptions of various protocols

Figure 5 represents a similar energy expenditure analysis while the parameter "mobility of the nodes" was given the highest priority. The proposed protocol outperforms the other two similar protocols under this circumstance also. The proposed protocol exhibits an improvement in terms of energy efficiency over other protocols under consideration such as RITMC and MCPS. This is again due to the factors like minimum channel switching, better selection of cluster head node. There is an average improvement of 4% over MCPS and 5% over RITMC while energy efficiency was under consideration, under the influence of AC-MAC.

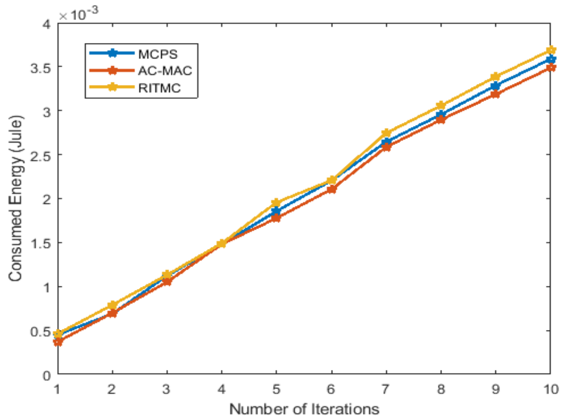

Figure 5 Energy consumptions of various protocols (while 'mobility' was assigned the highest priority)

Throughput: Throughput is a measure of how many units of information are delivered at the destination in a given amount of time. Throughput has been calculated in bits per second (bps). Figure 6 and 7 present the throughput analysis under the influence of the three protocols MCPS, RITMC and AC-MAC (proposed one). As before, figure 6 represents the respective performances of the protocols while priorities were not assigned to any of the parameters. The protocols' corresponding performances are shown in figure 7, with the AHP-based protocol giving the "mobility of the nodes" parameter the highest priority. In terms of throughput as well, the suggested protocol performs better than any others. MCPS and RITMC are two competing protocols; the suggested approach outperforms them in terms of throughput. There is an average increase of throughput by 22% over MCPS and by 28% over RITMC under the impact of the proposed protocol AC-MAC. This is due to the appropriate selection of cluster head node by using AHP based approach considering multiple parameters. Moreover, suitable channels have also been identified for data transmission using multiple parameters as per the AHP based protocol.

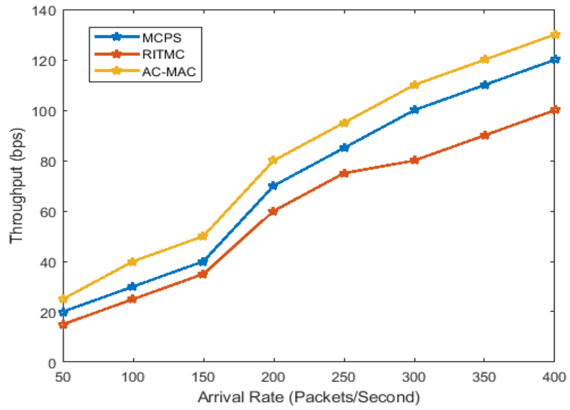

Figure 6 Throughput comparisons among the protocols

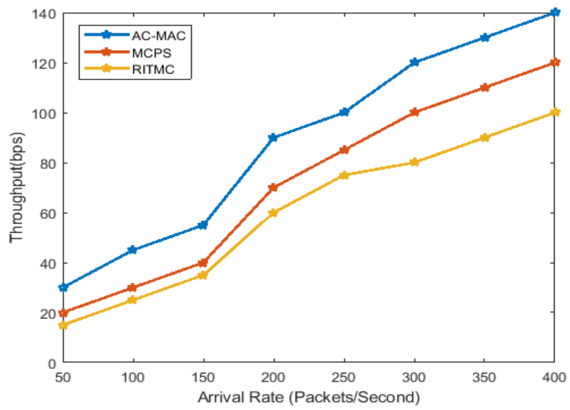

Figure 7 Throughput comparisons among the protocols (while mobility has the highest priority)

End-to-end delay: This performance parameter measures the time it takes for data to get to its destination across the network. It is measured in seconds. Figure 8 and 9 represent the performance of the protocols in terms of end-to-end delay. As before, the figure 8 represents a situation in which no priority was assigned to any of the parameters and figure 9 represents a situation in which the "mobility of the nodes" was given the highest priority, as per the requirements of the AHP based approach.

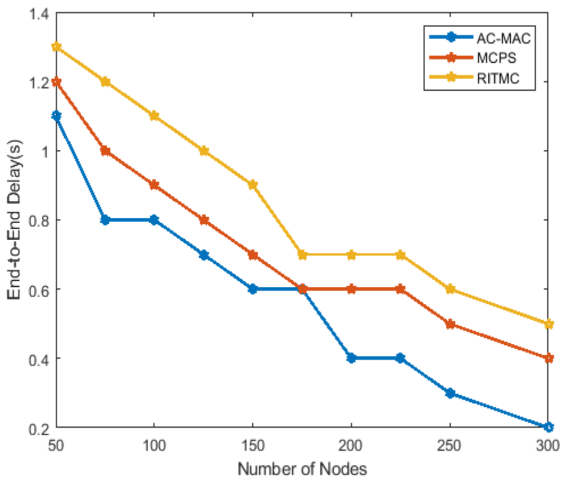

Figure 8 End-to-end delays of the protocols

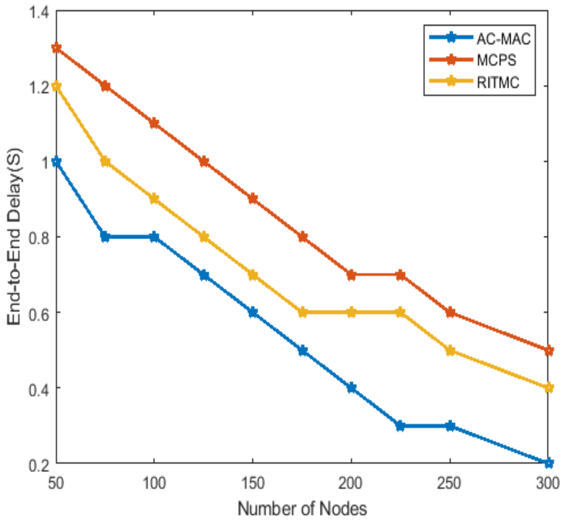

Figure 9 End-to-end delays of the protocols (while mobility has the highest priority)

In terms of end-to-end delay, the suggested protocol AC-MAC performs better than the other three protocols under consideration. The suggested protocol outperforms MCPS and RITMC in terms of end-to-end delay, on average, by 25.8% and 17.9%, respectively. Faster packet processing in intermediate nodes and the hierarchical communication architecture are mostly to blame for this improvement in end-to-end latency. More capable nodes have always been chosen as the cluster head node since queuing delay has been identified as one of the arguments in the planned AHP based protocol. This has led to faster packet processing.

Above simulation was done for QoS requirements like energy efficiency and throughput, when total node of the network 100. By varying the node density, the end-to-end delay was computed. Table 8 presents two scenarios: a typical scenario and a critical scenario, with corresponding parameter values displayed.

Table 8: parameter values during topology changes

Parameters	Normal situation	Critical situation
Link failure rate	(5-7) %	(10-15) %
Node failure rate	(5-7) %	(10-15) %
Mobility of the nodes	2-5 m/sec	7-10 m/sec

Figure 10 and 11 display energy consumption and throughput of AC-MAC protocol which is proposed in this paper under normal situation. The normal situation is when link failure rate and node failure rate are very low and at the same time mobile nodes also have a low speed. Here, node density is considered in the range of 100 to 500 nodes in the entire field.

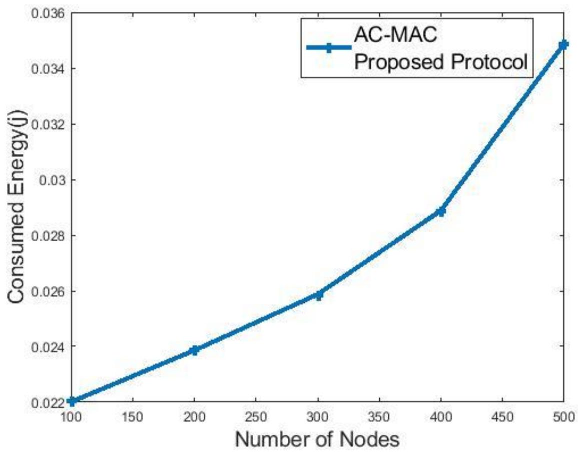

Figure 10: Energy consumption of AC-MAC protocol during normal situation

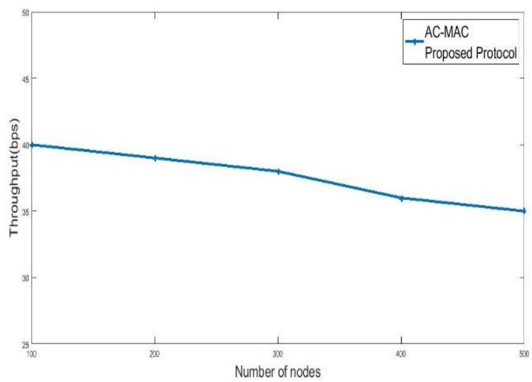

Figure 11: Throughput of AC-MAC protocol during normal situation

Figure 12 and 13 display energy consumption and throughput of AC-MAC protocol (proposed in this paper) during critical situation. Critical situation represents very heavy traffic condition; it also represents a network that is running for long period of time. Moreover, there is a high node failure rate and high mobility of the moving nodes, under critical situation. Node density is considered in the range of 100 to 500 nodes in the entire field.

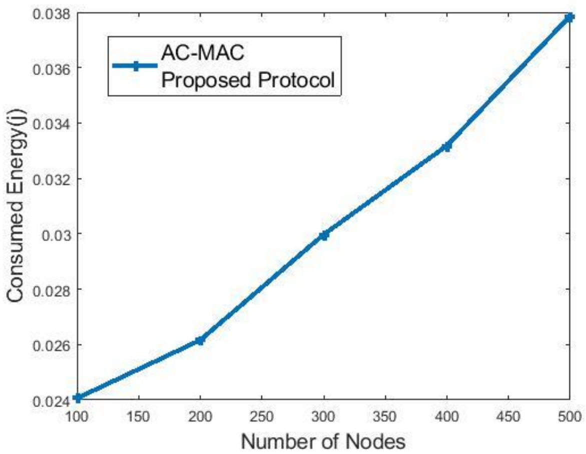

Figure 12: Energy consumption of AC-MAC protocol during critical situation

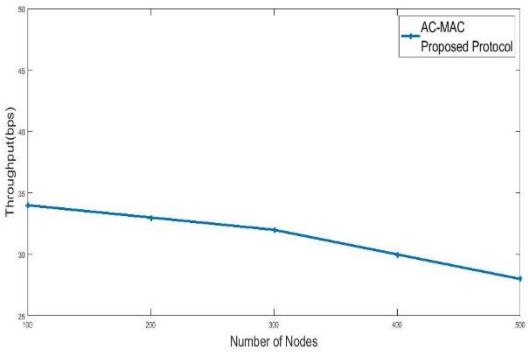

Figure13: Throughput of AC-MAC protocol during critical situation

One of the AHP criteria for channel allocation is channel same-ability. This criterion plays an important role for data transmission. It also contributes in cluster formation, by placing the nodes with same channels, inside the same cluster, if at all possible.

Data transfer taking place from the CH to the base station or sink via same or different channels is shown in figure 14. Channels are represented in different colors. Some communications are taking place through one channel (or the same channel) and some communications are taking place via multiple channels (which is achieved through channel switching). This indicates that data are being transmitted from the source to the destination node across two or even more separate channels. Under such circumstances, channel switching affects the energy efficiency and also throughput.

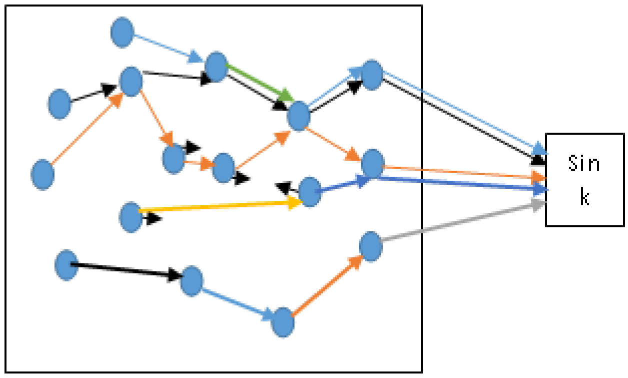

Figure 14: Data transmission through same channel and through multiple channels through channel switching

In figure 15, the effect of channel switching on energy consumption under the influence of the proposed protocol is shown. Here, four different situations are considered; *first situation*: same channel is used during entire data transmission from source to sink. Other three situations are as given below: *second*: one channel change, *third*: two channel changes, and *fourth*: three channel changes. It is observed that when channel switching increases, energy consumption also increases. Similarly, throughput is also affected due to channel switching (in figure 16). Throughput decreases when channel switching increases.

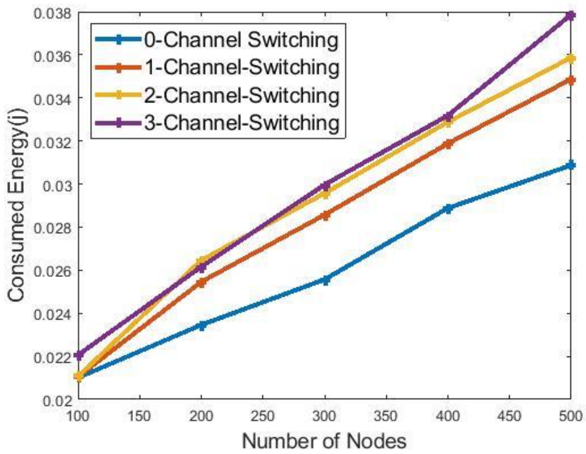

Figure 15: Energy consumption of AC-MAC protocol during channel witching

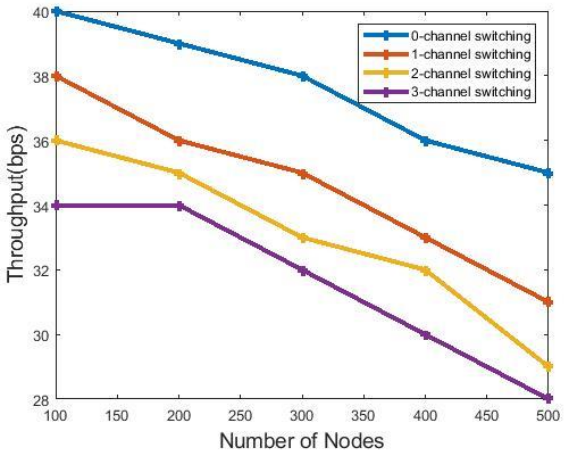

Figure 16: Throughput of AC-MAC protocol during channel switching

As a summary, it may be noted that the proposed protocol (AC-MAC) is effective in terms of throughput, end-to-end latency, and energy efficiency. Table 9 presents a comparison between different MAC protocols for MWSN including the proposed one (AC-MAC), considering QoS aspects.

Table 9: QoS requirements comparison among existing MAC protocols and the proposed protocol AC-MAC

Protocols	Quality of services parameters					
	Energy efficiency	End-to-end delay	Throughput	Packet delivery ratio	Network lifetime	Scalability
MCPS [10]	-	Yes	Yes	-	-	-
RITMC [12]	Yes	Yes	-	Yes	-	-
MSF-MAC [18]	-	Yes	Yes	-	-	-
MPCB-HM [19]	Yes	-	-	-	-	Yes
MOC-MAC [20]	-	-	Yes	-	Yes	-
QMMAC [22]	Yes	Yes	Yes	-	-	-
GCMAC [23]	Yes	-	Yes	-	-	-
Proposed protocol (AC-MAC)	Yes	Yes	Yes	-	-	-

5. CONCLUSION and FUTURE SCOPE

A cluster-based MAC protocol titled as AC-MAC protocol has been designed for multi-channel WSNs. In terms of energy usage, throughput, and end-to-end latency, this protocol operated effectively. The design of the suggested protocol makes use of the Analytical Hierarchy Process (AHP). AHP has seen a lot of applications in optimization, recently. The multi-channel WSN considered in this work constituted of static as well as mobile nodes. The sink is measured to be static. The sink is positioned outdoor the sensor field.

The two MAC protocols namely, RITMC and MCPS, were compared to see how well the proposed approach performed. The proposed protocol has performed better than the other two in terms of throughput, energy efficiency, and end-to-end delay. The performance of the AC-MAC protocol is improved due to various reasons including minimum channel switching, selecting the cluster head nodes that can handle more data packets for further processing (considering queuing length), and also selecting the cluster head nodes considering residual energy, etc.

In future, the proposed protocol AC-MAC may be simulated extensively and be compared its performance with many other similar protocols. Moreover, test bed implementation may be planned in the future.

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