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BINARY PARTICLE SWARM OPTIMIZED CLUSTERS FOR WIRELESS SENSOR NETWORK

Ramana Rao[1*] and Adilakshmi[2]
*[*1]Dept. of CSE, University College of Engineering, Osmania University, Hyderabad, INDIA*
[2]Dept. of CSE, Vasavi College of Engineering, Osmania University, Hyderabad, INDIA

ABSTRACT

Wireless Sensor Networks (WSN) is widely applied to many domains, including smart spaces, environmental monitoring, medical systems and robotic explorations. The networks constitutes of scattered sensor nodes that arrange automatically into multi-hop wireless networks. A node possesses one or more sensors, embedded processors, low-power radios and a battery. Data is transmitted through the network by routing. Clustering of nodes in the network helps to conserve energy of the nodes. In this paper, it is proposed to cluster B-MAC protocol with Binary Particle Swarm Optimization (BPSO). The suggested protocol's performance is tested for packet delivery ratio, end to end delay, hops and jitter. The outcome reveals that the new BPSO with cluster BMAC performs better than BMAC in either static or dynamic scenarios. Results show that the proposed method improved the PDR by 3.22% when compared to the BMAC (flooding) protocol at 40 kmph. The proposed method improved the average PDR by 3.30% when compared to the BMAC (flooding) protocol in various node mobility scenarios.

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KEY WORDS

Wireless Sensor Networks (WSN), Cluster Head (CH), Medium Access Control (MAC), Binary Particle Swarm Optimization (BPSO).

INTRODUCTION

Wireless Sensor Networks (WSN) possesses innumerable sensors distributed in a remote location. Their primary role is that collecting data from the surroundings and pass it on to a base stations [1]. WSN's disadvantage lies in the low energy of the sensors, and this remains a huge restriction for the employment of WSN. Network efficacy relies on the life span of sensor nodes and network coverage.

Once a network is positioned, it is impossible to change batteries. Hence, when WSN is designed, this has to be taken into account. Secondly, the speed at which data is moved from a node to the base station is important. The energy consumed may be decreased by utilizing a couple of nodes to connect with the base station. These nodes are cluster heads and information is collected in them prior to being transferred to a base station [2].

Network efficacy relies on cluster head selection and parameters for the selections. Clustering assures lesser communication overheads and effective resource allotments and so, decreasing the total amount of energy consumed. Disturbances amongst sensor nodes are decreased as well [3]. The obstacle in clustering is in the selection of appropriate nodes to be made cluster heads or gateways.

Cluster heads are hierarchically ordered. The main benefit of such hierarchical protocols is that cluster heads execute in-network data aggregation. Routing moves forward by passing on packets up a hierarchy until a sink node is reached. Flat routing protocols attempt to discover good quality routes from the source to the sink through flooding. Because flooding is an expensive operation in networks that are typically starved for resources, smart algorithms constrain flooding on specific areas [4]. Certain algorithms employ heuristics based probabilistic methods for establishing routing paths.

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Flooding policies primary roles are to determine meaning as well as calculate node ranks apart from employing a state machine governing singular packets life cycle on nodes [5]. Flooding policies are generally sorted according to these two characteristics.

WSNs typically have scarce resources. Conserving energy is crucial. A sensor nodes' radio utilized immense energy. Creating low power electronic gadgets to decrease energy consumed by sensor nodes is an area widely researched. Because of limits in hardware, additional energy efficacy can only be accomplished through the planning of energy efficient communication protocols.

Medium Access Control (MAC) is a method that ensured success in network executions. The primary role of MAC is to avoid conflicts from intervening nodes. Creating energy efficient MAC protocol is the method to extend network life [6].

WSN's MAC protocols have two goals. Firstly, for the purpose of creating sensor network infrastructure, many sensor nodes are employed and the MAC system constructs a contact link among the sensor nodes. Second is the sharing of the communication medium in a fair and effective manner.

However, there are certain features apart from energy efficacy that need to be deliberated upon. Effective utilization of energy improves network life. Some more features are how sensor networks respond to alterations in the size of the network and how it adjusts to changing environment dynamics. Alterations to topology, quantity of nodes or total network size ought not to have an effect on typical sensor network functions. MAC protocol ought to be capable of adapting to such features [7]. But, there are few attributes other than energy efficiency which should also be considered. Efficient energy use increases network life. Other attributes are how sensor networks react to changes in network size and how it adapts to changing environment dynamics. Changes to topology, nodes quantity or overall network dimensions should not affect normal sensor network functioning. MAC protocol should adapt to such characteristics.

B-MAC is a method grounded in CSMA, utilizing minimal power listening as well as a drawn out preamble for the purpose of minimal power communications. Nodes possess both 'awake' and 'sleep' sessions and each node have an autonomous timetable. If a node wishes to transfer data, it includes an information packet with a preamble that is longer than the recipient's sleep cycle. In the span of the awake period, a node skims a medium and once the preamble is spotted, it stays awake in order to get the information [8]. Because of the long preamble, the transmitter is sure that the recipient will definitely wake up during the preamble, spot it and stay awake to get information. With B-MAC, an interface where a program may modify sleep schedules to suit the varying traffic is ensured. Despite the excellent performance of B-MAC, there is the challenge of overhearing as well as the energy wasted in long preambles.

This paper suggests cluster based B-MAC with BPSO. Section 2 reviews related literature. Section 3 describes the methods employed in this work. Section 4 reveals experiment results and Section 5 concludes the work.

RELATED WORK

Utilizing receiver-based MAC protocols (RB-MAC) and adaptable RB-MAC in routing protocol for less energy and lossy WSN protocol in low-power/ lossy wireless channel studied by Akhavan et al., [9] led to a cross-layer method in which routing decisions depend on MAC-layer functions. Outcomes proved that RB-MAC and adaptive RB-MAC performed better than current topmost sender-based MAC protocols with regard to end-to-end energy-efficiency, delay and reliability. Simulations revealed that utilizing receiver-based MAC protocols in RPL-based lossy channel meant decreased retransmissions as opposed to sender-based MAC.

A model for Power-Control and Delay-aware routing and MAC protocol (PCDARM) for Energy constraint and delay sensitive WSN applications created by Rachamalla and Kancharla [10] plans to achieve routing of packets through multiple paths with the delay previously known and with energy/link reliability constraints, in the routing phase and TDMA based slot assignment in an energy efficient manner during MAC phase. The routing phase plan employs traffic splitting on multiple paths. WSN's differential delay, link stability and power restrictions are considered. Slot allotment in TDMA frames with sleep and awake cycles for network nodes lead to effective

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MAC phase energy control. Experimental outcomes showed the advantages of the suggested protocol over DEAR. Simulations revealed that packet delay decreased in PCDARM. It performed better in power consumption as well.

A duty-cycled, directional adaptive MAC protocol suggested by Bin et al., [11] called DA-MAC considered that negative impacts of movement whereas particular selected nodes with appropriate features as forwarders, attained excellent end-to-end latency. Experimental outcomes using NS-2 revealed that the DA-MAC showed amazing performance in end-to-end latency as well as power conservation in mobile WSN.

A new cross-layer duty-cycled MAC protocol having data forwarding to pipeline features called P-MAC suggested by Tong et al., [12] for WSNs, separates network sensor nodes into various grades around a sink. PMAC/RMAC performance is assessed with regard to packet delivery latency and energy efficacy using OPNET simulation.

A structure where MAC and routing protocols join hands in order to identify as well as reserve routes, order nodes in clusters and schedule availability to a transmission medium in a coordinated time-shared manner was suggested by Ruiz et al., [13]. The result was named QUAlity-of-service-capable clusTer-based Timeshared ROuting-assisted (QUATTRO) MAC protocol. It was assessed through simulation investigating multiple settings where varying numbers and node densities were taken into account. Outcomes revealed that the protocol had considerable overhead.

Taranovs and Zagursky [14] suggested a completely collision-free TDMA-based MAC protocol for a WSN cluster in which each node is one-hop away from neighbours in all clusters making sure that no routing protocols are required. It allows utilization of restricted sources sensor nodes extending WSN life. Higher level content denotes automatic runtime choosing of services executions and network sources to implement application specifications in resources-effective and context-aware scenarios.

Liang et al., [15] proposed a cross-layer protocol named CL-LEACH for effective power usage of clustered WSNs, grounded in Low Energy Adaptive Clustering Hierarchy algorithm (LEACH). Through the introduction of Frequency Shift Keying (FSK) as well as the consideration of constellation size as a global cross-layer variance, CL-LEACH regards physical, link, MAC and routing layers, integrating a battery non-linearity discharge model called FSK Orthogonal modulation scheme, TDMA and CSMA MAC protocols, and cluster routing algorithm. Experiments reveal that CL-LEACH reduces power usage by a great deal and extends clustered WSNs life as opposed to LEACH protocol.

MAC and routing protocols are a major component in WSNs for end-to-end data transmission. Additionally these protocols utilize a hierarchical architecture for end-to-end, dependable data delivery. Too much time and power is utilized in order to create a hierarchical architecture sequentially. In order to offset these obstacles, Dash et al., [16] proposed a distributed algorithm to create an architecture, whose hierarchy is such that the nodes possess two parent nodes apart from the root node. The novel approach decreased the average power usage of a node by setting other nodes in sleep mode in a dispersed manner as opposed to contemporary methods. The Castalia simulator was utilized to simulate the method and the results were contrasted with the contemporary sequential method.

An optimal, maximized configurable power saving protocol, named Green-MAC for corona based WSNs suggested by Lin et al., [17] possessed many advantageous characteristics such that Green-MAC utilizing a generalized Chinese remainder theorem ensures that two sensors in adjacent coronas wake up at the same bounded time, with no regard to their schedule or cycle lengths; in a cycle length, ATF-ratio (fraction of a cycle's awake time frames) of sensors attains a theoretical minimum; minimum ATF-ratio restrictions, amount of configurable ATF-ratios for sensors attains a theoretical maximum; ATF-ratio configuration scheme is proposed for Green-MAC so that WSN energy usage is decreased while worst event-to-sink delay need is accomplished with high probability. Theoretical study as well as simulation revealed that Green-MAC performed better than contemporary energy conserving protocols for corona-based WSNs, as well as Q-MAC/Queen-MAC with regard to configurability, ATF-ratio, delay violation ratio, network life and event-to-sink throughput.

A dependable cross layer routing scheme (CL - RS) to balance power to extend life by governed restricted power usage was suggested by Kusumamba and Kumar [18]. A combined optimization design was designed as a linear

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programming problem. Simulations revealed that joining CL-RS and CL-MAC algorithms at every layer improved network life considerably and that a relationship is present between network life maximization and dependability restrictions. The suggested method's performance was assessed under varying scenarios through ns-2. Out comes established that the new method performed better than layered AODV with regard to end-to-end delay, packet loss ratio, control overhead and power consumption.

A MAC-aware Routing protocol for WSNs (MAR-WSN) in which next hop decisions were dependent on TDMA scheduling and two-hop neighbourhood knowledge was suggested by Louail et al., [19]. Coherent routing protocol decisions in space, with those by MAC protocol, in time, showed itself to be effective against metrics such as power usage, delay and hop number. Simulations revealed the new method's excellent performance in medium/high density networks as opposed to current approaches.

A novel WSN routing method where routing is dependent on radio-aware metric possessing radio information at the MAC layer suggested by Tariq et al., [20] had data being forwarded to a determined neighbour, rather than flooding exploratory data into the entire network with directed diffusion. Simulations revealed the suggested routing method was around 4.3 times more effective with regard to power usage and 2.6 times more dependable with regard to data delivery as opposed to directed diffusion. The new scheme depended on interactions among routing/MAC layers to attain dependability and power efficacy using cross layer optimization.

METHODOLOGY

Binary PSO with cluster BMAC protocol is proposed.

Berkeley MAC (Flooding)

Berkeley Media Access Control (B-MAC) utilized in WSNs is a contention based MAC protocol. B-MAC is like Aloha with Preamble Sampling where BMAC duty cycles radio transceiver i.e. Sensor nodes turn ON/OFF continuously without missing the data packets. Preamble length is a parameter to upper layer guaranteeing optimal trade-off between power savings and latency or throughput. BMAC is almost identical to CSMA protocol having Low Power Consumption. BMAC utilizes unsynchronized duty cycling and long preambles to wake up receivers. BMAC improves dependability and channel assessment through a filter.

Sensor node change protocol operating variables such as back off values allowing a flexibility interface. BMAC utilizes an adaptive preamble sampling scheme to decrease idle listening and cut down duty cycle. B-MAC duty cycles a radio through periodic channel sampling called Low Power Listening (LPL). BMAC uses clear channel assessment (CCA) to determine if a packet arrives when node wakes up. If no packet has arrived a timeout puts the node to sleep again. BMAC utilizes CCA and packet back-offs for channel arbitration and link layer acknowledgments for dependability [21].

The first active node sends out control messages when its reconfiguration ends and other nodes flood once to coordinate with their neighbours in this approach. A node spends energy to send one up message and on receipt of multiple up messages from other nodes, polls the channel and sleeps for the remaining time.

It assumes polling interval for LPL during reconfiguration is T_p. Remember that T_p can be different than T_{lpl}. To wake up neighbours, nodes flood up messages with preamble T_p.

During flooding, a node needs to forward up message once. Let's assume average carrier sense is t_{cs}, and transmission time for up packet is t_{up}. A node's energy spent on transmission is

$$P_l t_{cs} + P_s\left(T_p + t_{up}\right)$$

A node receives n packets from n neighbours. And on average it overhears $T_p/2$ preamble for a packet. Energy it spends in receiving is

$$nP_l\left(T_p/2 + t_{up}\right)$$

As nodes reboot in uniform distribution, average waiting period before flooding for a node is T_d. Thus low-power listening cost on each node is

$$P_{poll} t_p T_d / T_p$$

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The final component of energy is sleep cost:

$$P_{slp}\left(T_p - t_p\right)T_d/T_p$$

Substituting Equations it obtains mean energy cost during reconfiguration as

$$\begin{aligned} E_{flood} &= P_l t_{cs} + P_s\left(T_p + t_{up}\right) \\ &+ nP_l\left(T_p/2 + t_{up}\right) \\ &+ P_{poll} t_p T_d/T_p \\ &+ P_{slp}\left(T_p - t_p\right)T_d/T_p \end{aligned}$$

Above equation shows a trade off with T_p. Increasing T_p reduces channel sampling frequency, and saves nodes from spending energy on polling. But it increases preamble length, thereby increasing transmission/overhearing cost. To reduce E_{flood}, it needs to obtain an optimal T_p from the following equation

$$\frac{dE_{flood}}{dT_p} = 0$$

Depending on data rate, B-MAC proposes a like approach to optimize polling period. But the analysis is grounded in periodic data traffic and does not guarantee a closed form formula. Rather during LPL with flooding network does not create periodic data and flooding of up messages [22] is the only traffic.

Proposed Binary Particle Swarm Optimization Cluster B-MAC

To use a mobility metric for clustering - a distributed, lowest mobility clustering algorithm, MOBIC, similar in execution to Lowest-ID algorithm - except that mobility metric is basis for cluster formation instead of ID information, is used. The algorithm is described in these steps:

- All nodes send/receive "Hello" messages to/from neighbours. A node measures received power levels of two successive "Hello" message transmissions from a neighbour, and calculates pair wise relative mobility metrics using (1). Before sending next broadcast packet to neighbours, a node computes aggregate relative mobility metric M using (2). M is represented through a double precision floating point number.
- All nodes start in Cluster Undecided state. A node broadcasts its own mobility metric, M (initialized to 0 at the start of computations) through "Hello" or "I'm Alive" messages to its 1-hop neighbours in every Broadcast Interval (BI). It is stored in a neighbour table of every neighbour with a timeout period (TP) arranged. The algorithm is implemented in a distributed manner. So, a node receives aggregate mobility values from neighbouring nodes, and compares its own mobility value with them.
- When a node has lowest value of M (aggregate relative mobility) among neighbours, it assumes Cluster Head status; otherwise it is a Cluster Member. The algorithm forms clusters which are two hops in diameter at the most. When a node is neighbour to two cluster heads, it becomes a "gateway" node. When two neighbouring nodes in a Cluster Undecided state have same M value it compares IDs and follows Lowest-ID algorithm.
- If mobility metrics of two cluster head nodes is same, and both contend to retain Cluster Head status, then cluster head selection is based on Lowest-ID algorithm wherein a node with lowest ID gets status of Cluster Head. When a node with Cluster Member status and low mobility moves into the range of another Cluster Head node with higher mobility, re-clustering does not happen (similar to LCC).
- In a mobile scenario, if two nodes with status Cluster Head move into each other's ranges, re-clustering is postponed for Cluster Contention Interval (CCI) to admit incidental contacts between passing nodes. If nodes are in transmission range of each other even after CCI timer expires, re-clustering is triggered, and a node with lower mobility metric assumes Cluster Head status.

A discrete binary version of PSO for binary problem was proposed by Kennedy and Eberhart where a particle's personal best and global best is modernized. The difference is the particles velocities. Such velocity has to be controlled in a range of [0, 1]. Each particle's velocity got using the equation:

$$\left\{ \begin{array}{l} v_{i,j}\left(t+1\right) = \eta\left(\begin{array}{l} v_{i,j}\left(t\right) + c_1 r_1\left(p_{ibest,j}\left(t\right) - x_{i,j}\left(t\right)\right) \\ + c_2 r_2\left(g_{ibest,j}\left(t\right) - x_{i,j}\left(t\right)\right) \end{array} \right) \\ x_{i,j}\left(t+1\right) = x_{i,j}\left(t\right) + v_{i,j}\left(t+1\right) \end{array} \right\}$$

where $v_{i,j}$ is particle velocity, $x_{i,j}$ is position of particle, t the number of iterations, c_1, and c_2 are two positive constants, called respectively as cognitive and social acceleration factors, r_1 and r_2 are random numbers in the range [0,1], and η is inertia weight. A particle's best position (pbest) is denoted as $p_{ibest,j}$ best position of all particles in a swarm is denoted as $g_{ibest,j}$.

$$\left\{ h\left(v_i\left(t+1\right)\right) = \eta \begin{pmatrix} v_{\max}, \text{ if } v_i\left(t+1\right) > v_{\max} \\ v_i\left(t+1\right), \text{ if } \left|v_i\left(t+1\right)\right| \le v_{\max} \\ v_{\min}, \text{ if } v_i\left(t+1\right) < v_{\min} \end{pmatrix} \right\}$$

Here v_i depends on the sigmoid function

$$sig\left(v_i\right) = \frac{1}{1 + l^{-v_i}}$$

Then the particle's position is updated as [23]

$$v_{i,j} = \begin{cases} v_{i,j}^1, \text{ if } ...x_{i,j} = 0 \\ v_{i,j}^0, \text{ if } ...x_{i,j} = 1 \end{cases}$$

RESULTS

In this study, BMAC (Flooding) and proposed BPSO cluster BMAC protocol are evaluated for WSN at static and various mobility levels. The results are analyzed from the following simulation values. The simulations are conducted to evaluate the performance of BMAC (Flooding), proposed BPSO cluster BMAC protocols under static and dynamic conditions. The Random Way point (RWP) mobility model is used, and the mobility is varied from 10 Kmph to 40 Kmph. Performance of BMAC (Flooding) and proposed BPSO cluster BMAC protocols were evaluated based on the Packet Delivery Ratio (PDR), End to End Delay, Number of hops, and Jitter for various mobility level in WSN.

Table: 1. Packet Delivery Ratio

Node mobility	BMAC (Flooding)	BPSO Cluster BMAC
Static	0.94	0.97
10 KMPH	0.89	0.92
20 KMPH	0.87	0.91
30 KMPH	0.83	0.86
40 KMPH	0.77	0.79

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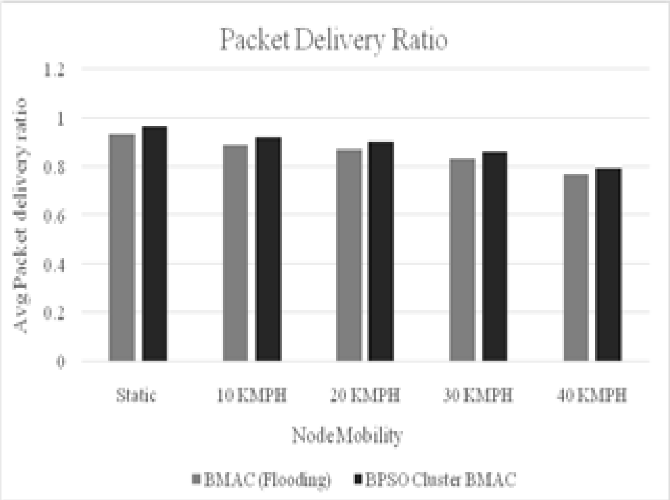

Fig: 1. Packet Delivery Ratio

The proposed method improved the PDR by 3.22% when compared to the BMAC (flooding) protocol at 40 kmph. The proposed method improved the average PDR by 3.30% when compared to the BMAC (flooding) protocol in various node mobility scenarios.

Table: 2. End to End Delay

Node mobility	BMAC (Flooding)	BPSO Cluster BMAC
Static	0.0012	0.0011
10 KMPH	0.0011	0.0011
20 KMPH	0.0011	0.0010
30 KMPH	0.0014	0.0014
40 KMPH	0.0072	0.0067

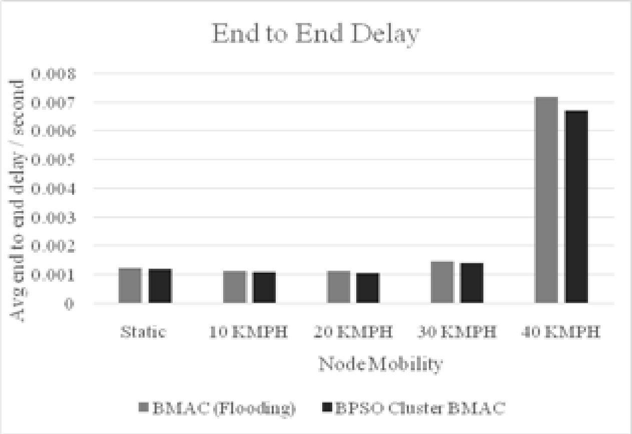

Fig: 2. End to End Delay

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The proposed method reduced the end to end delay by 6.78 % when compared to the BMAC (flooding) protocol in 40 kmph. The proposed method reduced average end to end delay by 4.26 % when compared to the BMAC (flooding) protocol in various node mobility scenarios.

Table: 3. Number of Hops

Node mobility	BMAC (Flooding)	BPSO Cluster BMAC
Static	4.1	4.4
10 KMPH	4.2	4.6
20 KMPH	6.0	6.9
30 KMPH	7.6	8.0
40 KMPH	7.8	9.2

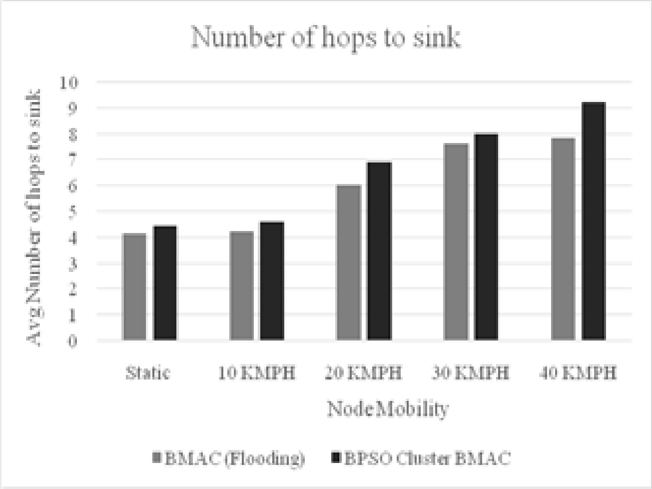

Fig: 3. Number of Hops

The proposed method increased number of hops to sink by 16.47 % when compared to the BMAC (flooding) protocol at 40kmph. The proposed method increased average number of hops to sink by 10.83% when compared to the BMAC (flooding) protocol in various node mobility scenarios.

Table: 4. Jitter

Node mobility	BMAC (Flooding)	BPSO Cluster BMAC
Static	0.0005	0.0005
10 KMPH	0.0012	0.0011
20 KMPH	0.0012	0.0011
30 KMPH	0.0013	0.0012
40 KMPH	0.0019	0.0018

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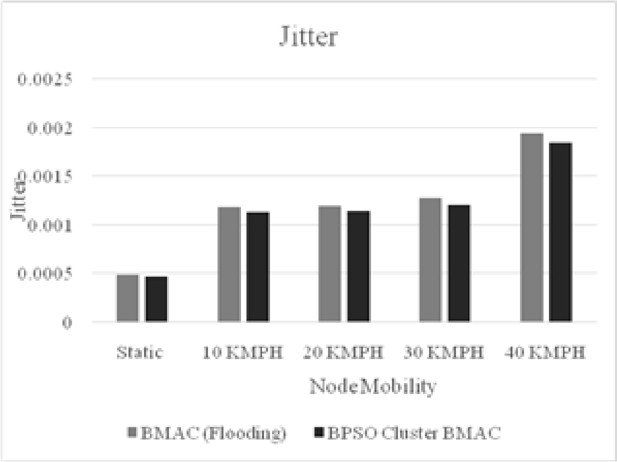

Fig: 4. Jitter

The proposed method reduced jitter by 4.88% when compared to the BMAC (flooding) protocol at 40 kmph. The proposed method reduced jitter by 6.23% when compared to the BMAC (flooding) protocol at 30 kmph.

CONCLUSION

Clustering of the network relies on the cluster heads to transmit data to the base station. This reduces energy spent by a sensor node to relay data from other nodes to a base station, which, in turn, potentially results in increased network life and larger amount of data delivery during network life. In this work, a BPSO based clustering for BMAC is proposed to improve the lifetime of the WSN and to improve the QoS. BMAC (flooding) and BPSO cluster BMAC protocols performance was evaluated based on Number of hops, End to End Delay, Packet Delivery Ratio (PDR), and Jitter for various mobility WSN levels. Results show that new BPSO cluster BMAC achieved better performance than BMAC (flooding) in static/dynamic scenarios. It was seen that high mobility degraded routing performance.

CONFLICT OF INTEREST

The authors declare no conflict of interests.

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The authors report no financial interests or potential conflicts of interest.

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