Research Journal of Applied Sciences, Engineering and Technology 9(11): 935-942, 2015
DOI:10.19026/rjaset.9.2586
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: September 24, 2014 Accepted: October 24, 2014 Published: April 15, 2015

Research Article

Fuzzy based Cross Layer Feed Back Mechanism for Mobility Aware Load Balanced Routing in WSN

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Abstract: Wireless Sensor Networks (WSNs) are made up of small nodes which have the ability to sense, compute and communicate wirelessly. Essential design issue in WSN routing is energy awareness as the sensors are energy constrained. Various routing, power management and data dissemination protocols designed for WSNs are available in the literature. Energy awareness and reliable data transmissions are handled in Medium Access Control (MAC) and Network layers. Decisions to achieve data reliability and energy efficiency trade-off were considered in layers. This study considers mobility, energy and link qualities to ward off poor link connectivity which reduce retransmissions and prolong WSN life. To achieve this, a fuzzy based cross layer protocol is proposed using an enhanced MAC protocol to provide better contention during mobility of the node and a network layer protocol based on link quality and mobility is proposed. Input to the fuzzy system is link quality and mobility. Output is decision for cluster head selection.

Keywords: Clustering, fuzzy logic, link quality, load balancing, Low Energy Adaptive Clustering Hierarchy (LEACH), Wireless Sensor Networks (WSNs)

INTRODUCTION

WSN's emerging field combines sensing, computation and communication into one device, forming a sea of connectivity through advanced mesh networking protocols. Such devices extend cyberspace reach into the physical world. As water fills all rooms in a submerged ship, mesh networking connectivity seeks and exploits communication paths by transmitting data from node to node searching for its destination. While any single device's capabilities are minimal, composition of hundreds of devices offer new technological possibilities.

WSN contains hundreds of sensor nodes with the ability to communicate among each other or directly to external base-station. Many sensors allow accurate sensing over geographical regions. Figure 1 reveals sensor node component's schematic diagram. A sensor node comprises sensing, processing, transmission, mobilizer, position finding system and power units (some components are optional e.g., mobilizer). The figure shows WSN communication architecture. Sensor nodes are spread in a sensor field, where they are deployed. They coordinate among themselves producing top quality information on physical environment.

Each sensor node bases decisions on mission, information it possesses and knowledge of computing, communication and energy resources. Each scattered sensor node can collect and route data either to sensors or back to a base station (s) which may be a fixed or mobile node capable of connecting a sensor network to communications infrastructure or to Internet where users have access to reported data (Al-Karaki and Kamal, 2004).

Routing determines a path between source and destination on data transmission request. Network layers implement incoming data routing in WSNs. In multi-hop networks, source nodes cannot reach sink directly. Hence, intermediate sensor nodes relay packets. Routing table's implementation is the solution as it has a list of node options for any packet destination. Routing table is the routing algorithm's task aided by routing protocol for construction and maintenance.

Depending on application, different architectures and design goals/constraints were considered for sensor networks as routing protocol performance is closely related to architectural model (Akyildiz *et al*., 2002) as follows.

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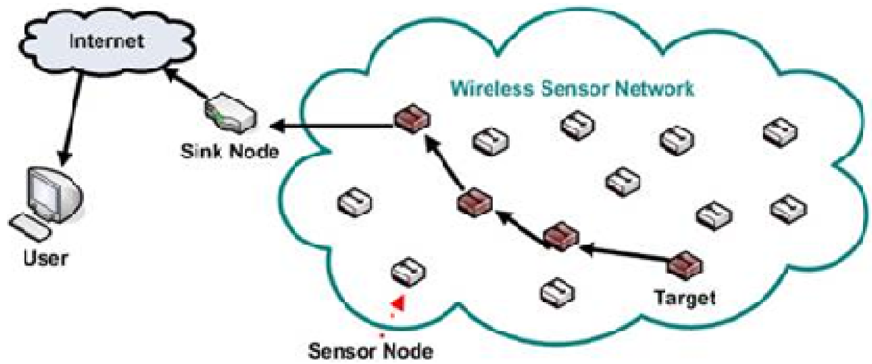

Fig. 1: Typical wireless sensor network

Network dynamics: Most network architectures assume sensor nodes are stationary, as there are very few setups that use mobile sensors.

Node deployment: It is application dependent and affects routing protocol performance. Deployment is either deterministic or self-organizing. Sensors are placed manually and data routed through pre-determined paths in deterministic situations.

Energy considerations: During infrastructure creation, setting up routes is influenced by energy considerations.

Node capabilities: In sensor networks, different functionalities are associated with sensor nodes.

Data aggregation/fusion: Similar packets from multiple nodes are aggregated to reduce transmission.

WSN Routing Protocols are classified in four ways based on the way routing paths are established, according to network structure, according to protocol operation and according to initiator of communications. Routing paths are proactive, reactive or hybrid. Proactive protocols compute all routes before being needed and store them in each node's routing tables. When a route changes, it is propagated throughout the network. As WSN consists of thousands of nodes, routing table of every node have to be maintained. They are huge and hence proactive protocols do not suit WSNs. Reactive protocols compute nodes only when needed (Lee *et al*., 2003; Akkaya and Younis, 2005).

WSN protocols require low-power and flexible hardware platform. WSN routing protocols aim to increase energy efficiency when transmitting data to a base station. Routing protocols are flat, hierarchical and location-based (Akkaya and Younis, 2005) depending on network structure. Traditional/Classical hierarchical routing tactics include distributed and centralized routings. In large WSNs, sensors are hierarchically organized into clusters, each with its Cluster Head (CH) (Kahn *et al*., 1999; Abbasi and Younis, 2007). Sensors in a cluster transmit data to CH in a cluster and this is forwarded to the sink, directly or via a multi-hop path through intermediate CHs. This was adopted by recent standard specifications for sensor networks like 802.15.4 standard and ZigBee Alliance specifications. Although it lowered individual sensor battery drainage greatly, it had to link up with immediate CHs over relatively short distances. Other advantages include simple network management, improved security and better scalability. High energy consumption is due to intra-cluster traffic to a CH transmitted single stream by it and relayed to CHs inter-cluster traffic. This is occasionally desirable due to power consumption advantages over direct (CH-to-sink) communication. CH traffic can be greater than individual sensor traffic due to sensors high density. The clustering paradigm increases CHs burden leading to battery depletion which is a disadvantage. Hence, Low Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman *et al*., 2000; Handy *et al*., 2002) is significant for WSN routing protocols.

Clustering object routing includes single and multi-hop communication (Farooq *et al*., 2010; Chen and Chen, 2013). In the former, sensor nodes reach destination directly; whereas in the latter, nodes have restricted transmission range forcing data to be routed through many hops to the destination. Both have unbalanced energy dissipation among nodes, resulting in some nodes losing energy and dying quicker than others, reducing sensing coverage and leading to network partitioning. In single-hop communication, nodes away from base station are most critical, while in multi-hop communication, nodes closer to a base station face heavy relay traffic and hence die first, causing "hotspots" (Abdulla *et al*., 2012a; Wang *et al*., 2010; Abdulla *et al*., 2012b).

Cross layer feedback is from upper to lower layer or vice versa. For example, application's delay or loss constraints are communicated to link layer to enable it to adapt an error correction mechanism; user defined application priority is communicated to TCP to increase application receiver window with higher priority. In another case, TCP packet loss information is handed over to the application layer to adapt sending rate accordingly; physical layer transmits power and bit-error rate information is communicated to link/Medium Access Control (MAC) layer to ensure error correction mechanisms.

This study proposed a novel routing protocol based on fuzzy logic. Input to the fuzzy system is link quality and mobility. Output is decision for cluster head selection.

LITERATURE REVIEW

A new method for flat routing in WSN using fuzzy logic was proposed by Dastgheib *et al*. (2011), which was fully distributed and all operations were by nodes. Fuzzy logic use increased speed, accuracy and routing power. As processes are local, it is useful for environments needing real-time processing. Evaluation showed the method to increase network life dramatically.

Fuzzy logic election of node for WSN routing was proposed by Babu *et al*. (2012) who developed a new way to elect a node among trustworthy nodes to route processes. This consumed network node energies based on Fuzzy logic applied on residual energy, trust level and base station distance. The new method elects an indispensible node to participate in routing among many nodes. So this method of node election for WSN routing conserves nodes energies which is smooth and thereby increases WSN life.

A fuzzy-Gossip routing protocol for energy efficient WSN was proposed by AlShawi *et al*. (2012), which suggested an energy-efficient routing protocol named Fuzzy-Gossip protocol that was a gossip protocol modification using fuzzy logic. The new protocol determined optimal routing from source to destination through selected best nodes from candidate nodes in forwarding paths favoring highest remaining energy and lowest distance to sink. Simulation result proved that application of the new method to control message forwarding improved performance and lowered overall energy consumption while increasing WSN life.

A Fuzzy logic-based Energy Efficient Packet loss preventive Routing Protocol (FEEPRP) was proposed by Misra *et al*. (2009) where the protocol adopted a routing algorithm imparting security regarding avoiding malicious nodes, preventing data loss and limiting use of excess energy. FEEPRP does not absorb any kind of digital signatures or message MAC for authentication, as latter produces high communication overhead. It exploits fuzzy decision making to avail an energy-efficient secure destination route. Simulation analysis revealed that FEEPRP imparts effective network security while ensuring improved network performance.

An efficient cross-layer routing protocol in WSN based on fuzzy logic was proposed by Jaradat *et al*. (2013), which determined an energy aware routing scheme based on WSN's cross-layer approach aimed at lowering overall consumed energy and increasing network life. Node's remaining battery reserve capacity, link quality and transmission power within local communication range was considered to determine next hop relay node to reach network sink. Parameters from various stack layers were presented to a fuzzy logic system controller to make a next hop routing decision. The proposed cross-layer algorithm's performance was evaluated using discrete event simulation.

Improving decision-making for fuzzy logic-based routing in WSN was proposed by Ahvar *et al*. (2013), who introduced Improved-fuzzy logic (I-fuzzy), an effective method to address fuzzy logic weakness regarding defining rules. I-fuzzy was tested in many scenarios using GloMosim simulator and compared to classic fuzzy logic approach and a traditional minimum hop routing. Results proved that I-Fuzzy outperformed other approaches as regards data delivery, energy conservation and load distribution.

FPGA based Fuzzy Link Cost Processor (FLCP) for energy-aware routing in WSN design and implementation was proposed by Haider and Yusuf (2005). FLCP objective was determining value of cost for a link between two sensor nodes so that sensor network life was maximized. The gateway FLCP in WSN, periodically invoked fuzzy routine to determine link cost between two sensor nodes. Once costs of all links to the single destination were computed, the route could determine using any shortest path algorithm.

A fuzzy inference system and ant colony optimization based approach to improve WSN performance in routing protocols was proposed by Rabelo *et al*. (2013) which presented a proposal to estimate routes quality using fuzzy systems to help directed diffusion routing protocol. The fuzzy system estimated route quality degree based on hop count and nodes energy level that compose a route. An ACO algorithm adjusted automatically the fuzzy system rule base to improve routes classification strategy, increasing network energy efficiency. Simulations showed that the new method was effective as regards three metrics packet loss rate, message delay to the sink node and time of death of first sensor node.

Fuzzy logic based snooze schema for WSN MAC protocol was proposed by Hyder *et al*. (2011), which presented WSN by a S-MACF (for S-MAC Fuzzy) where many nodes have to stay awake than expected. A protocol adjustment rid the requirement for nodes to be awake longer than other nodes. The customized edition improved energy efficiency and enhanced WSN life.

Fuzzy algorithms to maximize WSN routing life was proposed by Minhas *et al*. (2008). The distinguishing aspect was use of fuzzy membership functions and rule in cost functions design for routing objectives in this study. A range of simulation results got under various network scenarios revealed that the proposed method as superior to many well-known online routing heuristics, regarding obtained network life and average energy consumption.

A cross-layer framework for reliable and energy-efficient data collection in WSN was suggested by Di Francesco *et al*. (2011). The framework used an adaptive energy-aware module to capture application's reliability requirements. MAC layer is automatically configured to reduce power consumption based on captured requirements, network topology and traffic conditions. ADaptive Access Parameters Tuning (ADAPT), a low-complexity distributed algorithm was proposed to meet application-specific reliability. The new method is incorporated with IEEE 802.15.4/ZigBee sans modification. Simulation illustrates ADAPT's energy-efficiency with near-optimal performance.

MAC and Efficient Routing Integrated with support for Localization (MERLIN), a cross-layer protocol using MAC and routing features was presented by Ruzzelli *et al*. (2008) which use multicast upstream and downstream approaches to relay packets to and from a gateway. Asynchronous burst ACK and negative burst ACK messages notify reception and transmission errors. Results reveal that MERLIN reduced latency and yielded extension to network life.

METHODOLOGY

This study considers mobility, energy and link qualities to ward off poor link connectivity reducing retransmissions and to prolong WSN life. A cross layer protocol is proposed using an enhanced MAC protocol to achieve this and provide better contention during node mobility and a link quality based network layer protocol.

LEACH is a WSN energy-conserving routing protocol. It forms cluster of sensor nodes based on signal strength and uses them as routers to forward other cluster nodes data to base station. Data processing is through cluster-heads. LEACH is a dynamic clustering mechanism. Time is divided into equal length intervals. At a round's starting, cluster-heads are generated randomly among nodes having higher remaining energy than the average remaining energy of other nodes.

Every sensor node n generates a random number so that 0< random <1 comparing it to a pre-defined threshold T (n). If random <T (n), sensor node becomes cluster-head in that round, or else it remains a cluster member. Threshold T (n) can be computed as follows:

$$T(n) = \frac{P}{1 - P\left(r \bmod \frac{1}{P}\right)} \quad \forall n \in G$$

In this formula:

p = Cluster heads percentage over all network nodes
r = Number of selection rounds
G = The set of nodes unselected in round 1/p

Cluster heads selection is totally random. After becoming cluster heads, nodes broadcast messages to nodes to inform their status. Non cluster-head nodes decide which cluster head to join based on messages receiving signal strength.

Cluster-heads create schedules sending them to all cluster nodes. For the remaining round, nodes send data to respective cluster head nodes, after which cluster heads aggregate and send data to base station (Abad and Jamali, 2011).

Figure 2 shows the working mechanism SMAC. The upward arrow represents sending messages and down arrow represents receiving messages; information flow represents sending and receiving messages sequence, while nodes are always in a monitoring state, under information flow represents sending and receiving messages sequence adopting S-MAC protocol.

S-MAC protocol design features:

Periodic monitoring and sleeping mechanism: In application environment, load flow of many sensors is not large, i.e., sensor nodes are in an idle monitoring state usually. Energy consumption in an idle monitoring state is the reason for nodes invalid energy consumption. S-MAC needs periodic monitoring and sleeping mechanism to solve idle monitoring issues. A complete monitoring and sleeping cycle is named one frame; monitoring in one frame is called active time. Before nodes send data, they broadcast their scheduling list to neighbor nodes and take same monitoring and sleeping scheduling node to form a virtual cluster.

Avoid crosstalk: In traditional IEEE 802.11 network, nodes monitor all data from neighbor nodes, even when they are not target nodes of packets. Also, in S-MAC when received destination node is not their RTS or

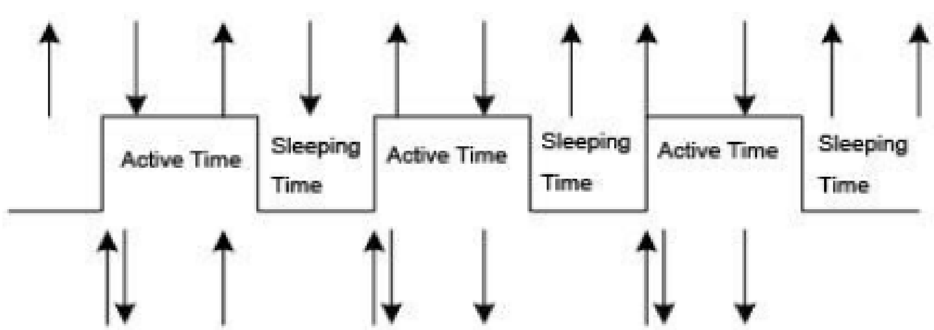

Fig. 2: S-MAC work mechanism

CTS packet-nodes go into a sleep state till data transmission is completed, to avoid crosstalk problem.

Data transmission: In 802.11 networks, long data is separated into many short data; transmission of such short data is done through a RTS/CTS/DATA/ACK handshake process. This leads to high control information cost. After S-MAC does once handshakes, it transmits short messages to solve the issue (An, 2012). The new algorithm is a cross layer protocol with improvements in MAC layer over S-MAC by:

- Introduction of mobility based variable frame time instead of fixed frame time used in S-MAC
- Initiating handover before mobility based link failure and link quality using information from upper layer
- LEACH modification for load balancing

Fuzzy Logic (FL) (Bonissone, 1980) is used in this study as perceptive reasoning's main implementation. FL imitates human thought, which is not as rigid as calculations performed by computers. FL offers many unique features making it a good alternative to control problems. It is robust as it need not be precise, requires noise-free inputs and is programmed to fail safely. Output control is a smooth control function despite wide input variations. As FL controller, processes user defined rules governing target control system, it is modified and tweaked easily to improve or alter system performance drastically.

Fuzzy Logic deals with information analysis using fuzzy sets, which represent a linguistic term like "Warm", "High" etc. Fuzzy sets are described by real values over which a set is mapped and called domain and membership function. A membership function assigns truth value between 0 and 1 to every point in fuzzy set's domain. Based on shape of membership function, varied fuzzy sets, like triangular, beta, PI, Gaussian, sigmoid etc., are used.

A fuzzy system has the fuzzifier, inference engine and defuzzifier. The fuzzifier maps every input value to corresponding fuzzy sets assigning it a truth value or degree of membership for every fuzzy set.

In this study, the input to fuzzy system is link quality and Mobility. Output is decision for cluster head selection. MIN-MAX inference technique was used in fuzzy controller. To locate a crisp output value from solution fuzzy region, controller uses centroid defuzzification method. Centroid defuzzification finds balance point of solution fuzzy region by calculating fuzzy region's weighted mean. Mathematically, crisp output domain value R, from solution fuzzy region A, is given by:

$$R = \sum_{i=0}^{n} W_i \mu_A (W_i) / \sum_{i=0}^{n} \mu_A (W_i)$$

where,

W_i = Domain value corresponding to rule i
n = Number of rules triggered in fuzzy inference engine
$\mu A\ (W_i)$ = Predicate truth for that domain value (Haider and Yusuf, 2009)

RESULTS AND DISCUSSION

This study considers mobility, energy and link qualities to ward off poor link connectivity reducing retransmissions and prolong WSN life. To achieve this a cross layer protocol is proposed using an enhanced MAC protocol to provide better contention during mobility of the node and a network layer protocol based on link quality is proposed. Input to the fuzzy system is link quality and Mobility. Output is decision for cluster head selection. The results are shown from Fig. 3 to 6.

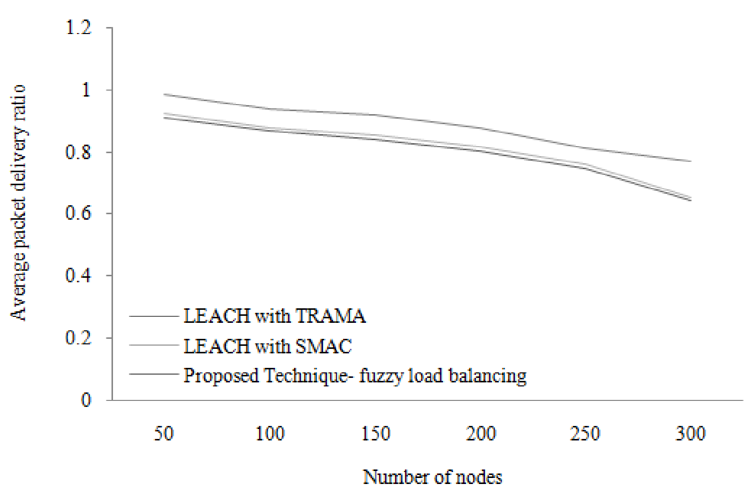

Fig. 3: Average packet delivery ratio

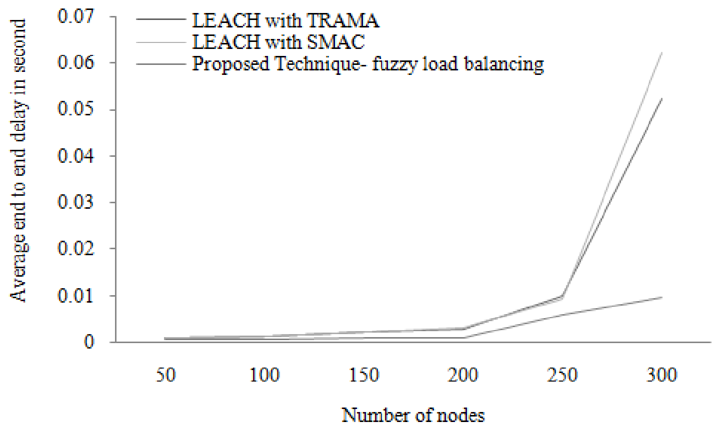

Fig. 4: Average end-end delay in seconds

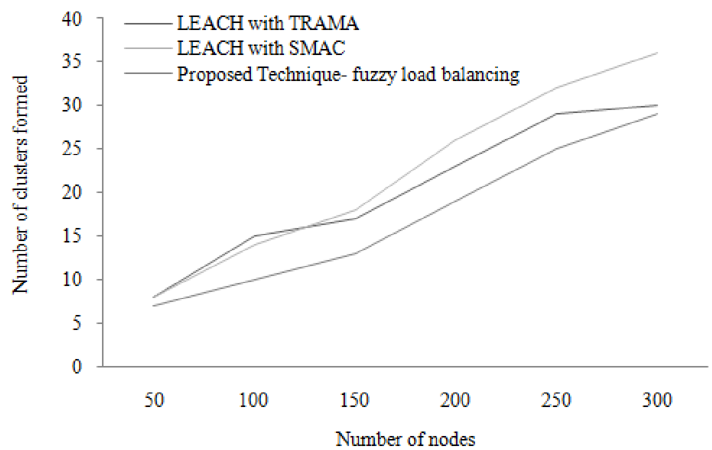

Fig. 5: Number of clusters formed

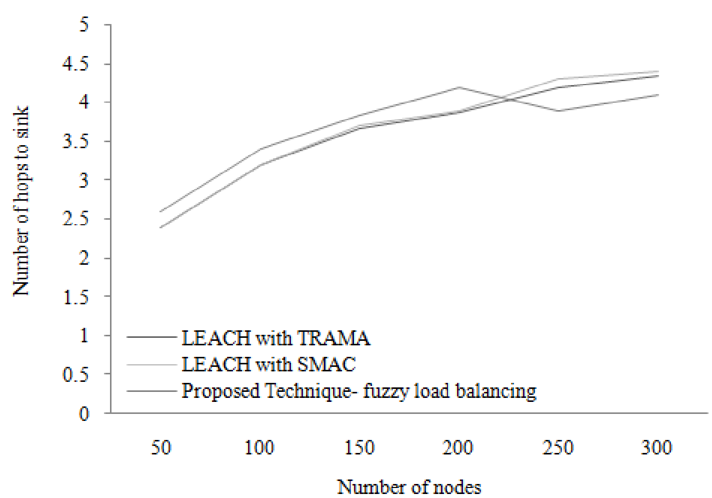

Fig. 6: Number of hops to sink

The proposed methodology improves the average PDR by 10.02% compared to SMAC and 8.57% compared to TRAMA. From Fig. 3 it can be seen that the average PDR scales well as the number of sensor nodes is increased (Table 1).

Table 2 shows the obtained end to end delay. End to End delay becomes important due to the mobility of the node and multiple hops to reach the sink. The end to end delay tends to increase with increase in the number of nodes. The performance of the proposed protocol is

Table 1: Average packet delivery ratio

Number of nodes	LEACH with TRAMA	LEACH with SMAC	Proposed technique-fuzzy load balancing
50	0.9112	0.9217	0.9824
100	0.8672	0.8743	0.9356
150	0.8418	0.8522	0.9185
200	0.8028	0.8143	0.8779
250	0.7465	0.7622	0.8133
300	0.6452	0.6543	0.7696

Table 2: Average end to end delay in second

Number of nodes	LEACH with TRAMA	LEACH with SMAC	Proposed technique-fuzzy load balancing
50	0.000815	0.000723	0.000678
100	0.001003	0.000904	0.000797
150	0.002013	0.001955	0.000933
200	0.002632	0.002895	0.000986
250	0.009678	0.008972	0.005806
300	0.052180	0.061974	0.009528

Table 3: Number of clusters formed

Number of nodes	LEACH with TRAMA	LEACH with SMAC	Proposed technique-fuzzy load balancing
50	8	8	7
100	15	14	10
150	17	18	13
200	23	26	19
250	29	32	25
300	30	36	29

Table 4: Number of hops to sink

Number of nodes	LEACH with TRAMA	LEACH with SMAC	Proposed technique-fuzzy load balancing
50	2.40	2.4	2.60
100	3.20	3.2	3.40
150	3.67	3.7	3.84
200	3.88	3.9	4.20
250	4.20	4.3	3.90
300	4.35	4.4	4.10

much better due to the faster handover as the link quality starts decreasing and the increased frame time during low mobility. The average end to end delay decreases by 72.59% compared to TRAMA and by 75.81% compared to SMAC protocol. Figure 4 shows the plot of the average end to end delay (Table 3).

Figure 5 shows that the proposed protocol decreases number of clusters formed by 15.57% compared to SMAC and 23.13% compared to TRAMA (Table 4).

Figure 6 shows that the proposed protocol increases number of clusters formed by 1.57% compared to SMAC and 0.64% compared to TRAMA.

From the above discussion, it can be seen that performance of the WSN improves significantly with the use of the proposed fuzzy logic. End to end delay and number of clusters in the proposed method reduces considerably when compared to LEACH. Though, the number of hops to sink increases in the proposed method higher packet delivery ratio is achieved.

CONCLUSION

WSN are constrained by energy, computation and communication resources making efficient energy management critical. This study uses historical link status data for consideration of forwarding decisions to achieve energy efficiency network trade-off. The new method selects path based on link quality's historical states. Energy and link qualities to ward off poor link connectivity are achieved, reducing end to end delay and prolonging WSN life. Based on link quality cluster head is formed and load amount that passed through the cluster head. The proposed method is compared against LEACH protocol. The simulation results demonstrate the effectiveness of the proposed protocol with respect to reduced end to end delay and number of clusters formed and improved packet delivery ratio.

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