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Design of A Fuzzy-controlled Energy - Efficient Multicast Scheduler (FEMS) For SDWSN

Anuradha Banerjee

Dept. of Information Systems, Indian Institute of Management, Shillong, Meghalaya, India.E-mail: anuradha79bn@gmail.com

Abstract

Multicasting is an important operation in software-defined wireless sensor networks (SDWSNs). In this operation, a group of nodes specified by their unique node identification numbers is supposed to receive the same multicast message at the approximately same time, if possible. These nodes are termed as multicast members or multicast destinations. They need not be physically close to one another to form a group. The present article proposes an energy-efficient scheduler exclusively for multicast operation in the SDWSN environment. Based on the advantages provided by underlying network architecture, a router can efficiently schedule multicast packets belonging to various multicast sessions. This promotes greenery in the network and significantly increases the packet delivery ratio. These claims are supported and justified by the experimental results presented in this paper. As far as the authors know, there is no multicast packet scheduler in the literature of wireless sensor networks or WSN. SDWSN is a more advanced version, and no multicast protocol has yet been proposed for these kinds of networks. Therefore, while designing the present fuzzy scheduler, we kept in mind all standard multicast protocols in the WSN environment.

Keywords: Energy efficiency, Fuzzy scheduler, Multicasting, Software-defined wireless sensor networks, Urgency.

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Introduction

Tree vs Mesh-based Multicast

In standard WSN (Banerjee, et al, 2016) environment, there are mainly two variants of multicast communication structure – tree and mesh. Tree-structured multicast transfers multicast packets from source to a recipient through only one pre-selected optimum route. But this structure is not reliable in general because if the route breaks out due to energy scarcity of any node, then the source will lose its connection with the desired recipient. In order to build a new route to that destination, the source will have to broadcast route-request, mentioning the same recipient as the destination. The process will eat up a lot of energy, possibly yielding some more route breakages. More route breakages mean the injection of more route-requests in the network.

On the other hand, there is more than one route from source to each multicast destination in mesh-based protocols. This provides good reliability than tree structure because if one route breaks, there lies at least one additional option to try before broadcasting route-request to broken links. But if routes do not break, then mesh-based multicast consumes more energy than a tree-based one. Our fuzzy scheduler assumes that a source is free to decide its preference for a tree or mesh multicast structure in the network. That is mentioned in the first data packet of each multicast session. The preference field is set to 1 for tree and 2 for the mesh. It has a significant influence on the way a scheduler prioritizes each packet. Our Fuzzy Energy-efficient Multicast Scheduler (FEMS) is embedded in each node in SDWSN to enable the green delivery of multicast packets to all multicast recipients at the approximately same time.

What is SDN?

Software-defined networking (SDN) is a recent trend of the network that introduces the idea of eliminating tight coupling between control and forwarding planes (Duan et. Al, 2018). The network can be broadly divided into three components – a centralized controller, hosts, and switches that connect a pair of hosts or switches or a host-switch pair. Northbound and Southbound application programming interfaces (APIs) are there to establish communication between various network entities. The centralized controller has the responsibility of configuring forwarding planes (popularly termed as flow tables) according to which the switches forward packets during communication. The basic structure of an SDN appears in figure 1.

SDN is deployed in various types of networks – like LAN, MAN, WAN, data center networks, etc. The advantages are flexible network control without sacrificing forwarding performance, ease of implementation, administration, and ample opportunities for reducing energy consumption. SDN has proven to be extremely successful in highly scalable data centers extending from private enterprises to public sectors were managing big data is not the only issue (Leccese, et. Al ,2015) thousands of new data are being generated every day to satisfy the requirements of various applications initiated by different levels of users. Open flow based SDN data centers have set a new trend as far as performance efficiency is concerned. Scheduling the flows to various ports is a very important component of network flow control. Also, occasional deactivation of switches is required to preserve energy. The reduction of energy consumption is an important aspect of efficiency in SDN.

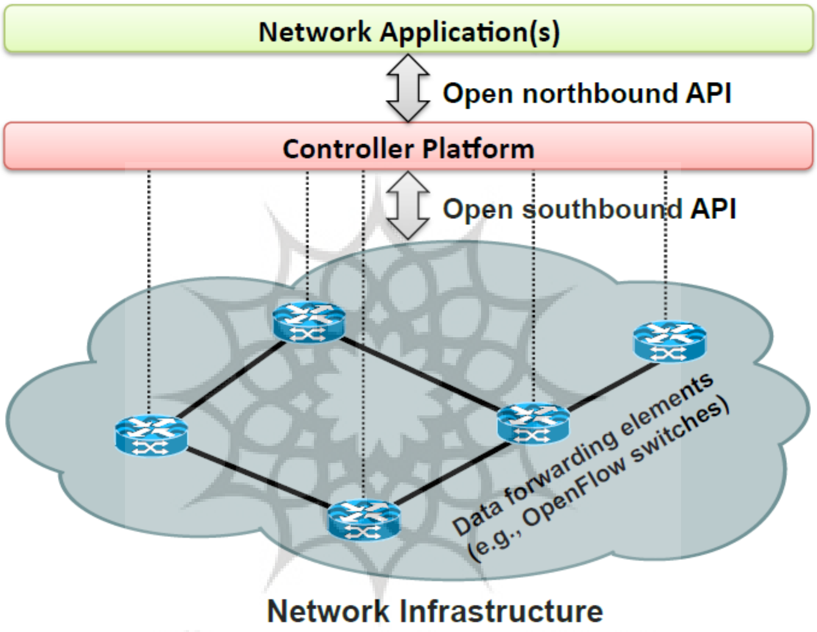


Figure 1. Structure of an SDN

Contributions of the Present Paper

The authors are confident that

i. FEMS is the first scheduler for multicast packets in the SDWSN framework.

ii. FEMS is energy efficient. It rearranges multicast packets generated by various sources destined to various recipients so that a lot of energy is saved in nodes.

iii. FEMS utilizes route information of packets. This represents the sequence of nodes through which the multicast packet is about to travel. Suppose many multicast members belonging to the intended group exist in the route mentioned in the multicast packet. In that case, FEMS increases the multicast packet's priority because of the merit of its path. Many multicast recipients of the intended group are expected to receive the same message in one shot through this path.

iv. FEMS identifies two components of the urgency of a packet. If the packet is to be forwarded through a fragile link, then it is good to forward it early, before the probable occurrence of link breakage. Another component of urgency is the delay. If a packet has already suffered from a huge amount of delay in the current router's predecessors, it is better to give the packet some relief in the current router by forwarding it fast. This helps in keeping parity in processing times gifted to different multicast sessions by network nodes.

v. Simulation results firmly establish that FEMS embedded version of state-of-the-art multicast protocols in WSN suffer from much lesser message cost and energy consumption than FCFS (first-come-first-served) versions of these protocols. Also, FEMS helps to improve the packet delivery ratio.

Organization of the Article

A brief survey of multicast protocols in WSN appears in section II. Section III shows the network layout. Section IV describes FEMS in detail. Simulation results appear in section V while section VI concludes the paper.

Method

i) Design of the study

Each node is equipped with four message queues corresponding to unicast, multicast, broadcast, and geocast packets. Whenever a new message packet arrives, its first field is checked. It is set to 1 for unicast, 2 for multicast, 3 for broadcast, and 4 for geocast packets. If the current packet is detected as multicast, the FEMS scheduler is activated, as shown in Figure2. There is a fuzzy controller named FUZZ-RANKER in FEMS scheduler that computes the priority of a process and accordingly places the newly arrived multicast packet in the multicast queue of the current node.

FUZZ-RANKER consists of two modules – namely, module 1 and module 2. Module 1 is concerned with calculating its input parameters' values, while module 2 implements its rule bases, as shown in figs 3a, 3b, 3c, and 3d. Input parameters of FUZZ-RANKER are member-presence, fragility-index, and delay-index. Computation of fragility-index depends upon a factor Q, which comprises the impacts of average transmission success or ats, average duration, or adur.

Figure 2: Flowchart of packet type detection

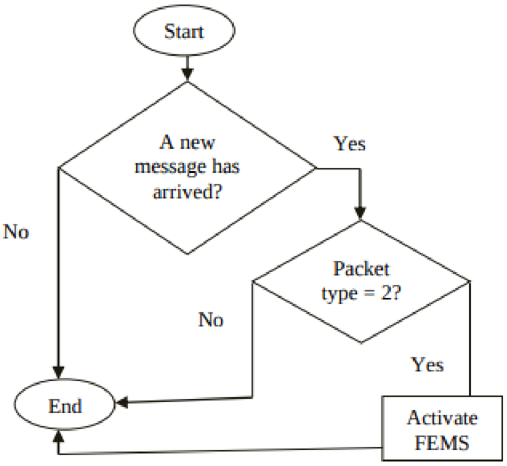


Fig 3a. Flowchart of FEMS activation

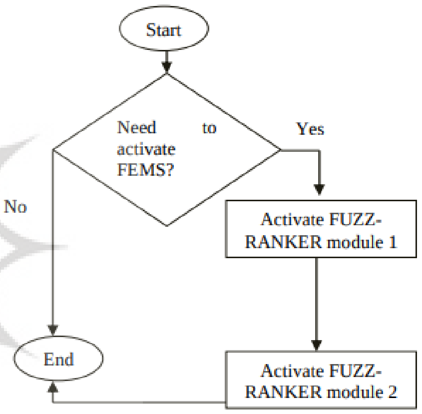


Fig 3b. Computation of Q

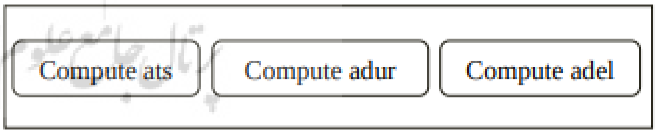


Figure 3c. Computation of input parameters of FUZZ-RANKER

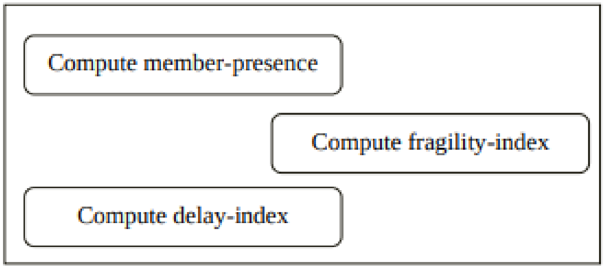
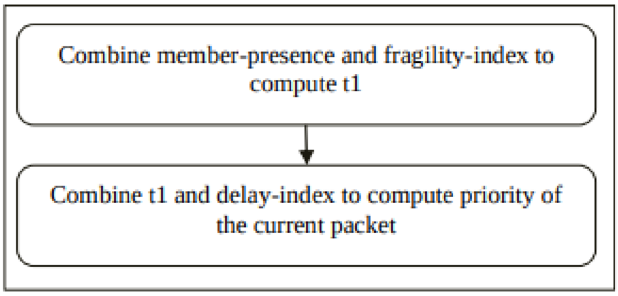


Figure 3d. Implementing fuzzy rule bases of FUZZ-RANKER



ii) Power Calculation

Please consider figure 4, wherein a route R, two consecutive routers n_i, and n_j are there. Let their coordinates at the current time t, be denoted as $(x_i(t), y_i(t))$, and $(x_j(t), y_j(t))$. Then their Cartesian distance at time t will be $\sqrt{\{(x_i(t) - x_j(t))^2+(y_i(t) - y_j(t))^2\}}$. Since n_i is the predecessor of n_j in R, n_i will deliver or forward the data packets generated by the source of R, to n_j.

Fig 4. Route R (n_s and n_d are the source and destinations: colored in red while the routers are blue)

As per Frii's transmission equation, received signal strength $Pr_j(t)$ of the signal transmitted by n_i to n_j at time t, is expressed below:

$$Pr_j(t) = C\ Pt(i)\ /\ \{(x_i(t) - x_j(t))^2 + (y_i(t) - y_j(t))\}^2$$

Where Pt(i) is the transmission power of n_i, and C is a constant.

Let $Pr_j(min)$ be the minimum signal strength required by n_j to properly receive a signal from any uplink neighbor.

So,

$$Pt(i) = Pr_j(min)\ \{(x_i(t) - x_j(t))^2 + (y_i(t) - y_j(t))\}^2/C$$

According to the study of discharge of batteries heavily used in ad hoc networks, at least 40% of total battery power is required to remain in operable condition; 40% - 60% is satisfactory, 60% - 80% is good, whereas 80% - 100% is considered to be more than sufficient. In FEMS, a node is always switched on unless its residual energy $(E_j - e_j(t))$ is at least (0.4 × E_j). Here E_j and $e_j(t)$ indicate the maximum battery capacity of n_j and consumed energy in the same node by time t.

iii) Intervention and Comparison

FEMS is a scheduler. It can be implemented and embedded with any multicast protocol. In the simulation section, we have compared FEMS embedded state-of-the-art multicast protocols with their ethnic versions. Simulation metrics are Message Cost, Energy Consumed, Network Throughput, and Average Delay.

Popular Energy Efficient Multicast Protocol

Among energy-efficient multicast protocols in WSN, these are state-of-the-art – Bats Energy Efficient Multicast Routing Protocol (BEMP), Group Multicast Protocol (EGMP),Minimum Energy multicasting with Adjusted Power (MEMAP). Local Minimum Cost Spanning Tree, and Protocol for Unified multicasting (PUMA).

BEMP forms a multicast tree structure where exactly one route is established from a multicast source to each multicast group recipient. But a tree structure cannot be efficient if the links are not stable. MEMAP takes as input the graph of the whole network. An auxiliary graph is constructed where each node n_i adjusts its transmission power corresponding to its distance from each downlink neighbor n_j. Then this auxiliary graph is reduced to a minimum energy transmission tree. But the disadvantage of BEMP is applicable here also. Poor link quality in the multicast trees hampers the reliability of the system. Moreover, the network and the auxiliary graph's construction is very difficult if the number of network nodes is very high. This may cause a bottleneck at the centralized station where an auxiliary graph and multicast trees are stored.

Local minimum cost spanning trees are constructed. Distributed Learning Automata is applied in this approach to make it energy efficient. EGMP converts multicast to geocast where the geocast region is a portion of the network, which comprises of all the multicast members. This improves the packet delivery ratio but suffers from a huge number of unnecessary transmissions. Message cost will be extremely high if all multicast members are placed very far apart. In PUMA, each multicast group elects a core that receives a multicast message from a multicast source and forwards it to the recipients connected to it through the shortest path. But the shortest path is not necessarily energy-efficient.

Network Layout

The software-defined wireless sensor network framework consists of the following layers, as shown in figure 5.

i. Physical layer (PL)

Multiple sensor nodes exist at this level. They communicate with the SDN controller using Openflow protocol to receive instruction in flow table information. Flows are directed according to it. Please note that nodes are divided into certain zones, and each zone is under the supervision of exactly one controller.

ii. Virtualization layer (VL)

The sensor network's key nodes in the physical layer map to virtual key nodes to form the virtual node layer (virtual layer).

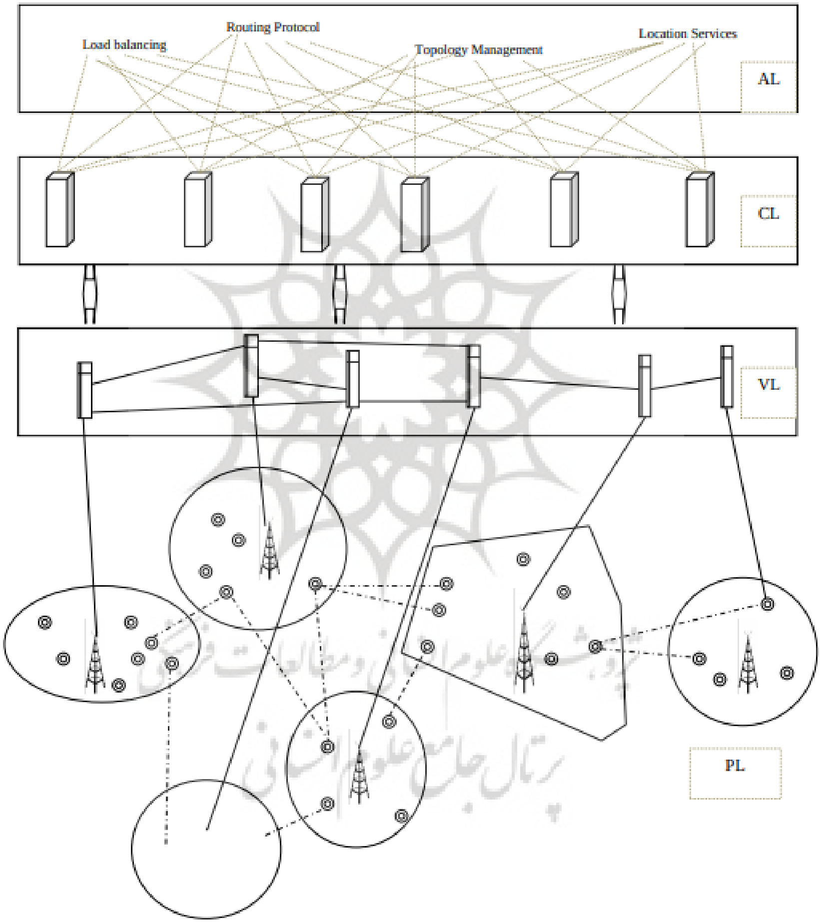


Figure 5. Network Framework

iii. Control layer (CL)

This layer consists of SDN controllers, which control routing, sleep monitoring, and other services and network management components. It communicates its flow control instructions to individual nodes using Openflow protocol. Based on location, radio-ranges, battery power, etc. information, an optimum route is selected from one node in the current zone to some other node (maybe in the same or different zone) an optimal route is selected.

iv. Application layer (AL)

The application layer defines the working policy for each application. Deciding the working strategy requires information about network topology and node status, available from the control layer. These strategies decide how services will be provided to sensor nodes.

FEMS in Detail

Multicast Message Format

Information fields in a multicast message are as follows:

i. must-src-id – This is the identifier of the multicast source node.

ii. Session-id – This specifies the identifier of the multicast session.

iii. mult-route - The sequence of node identifiers in the multicast route is shown in this field.

iv. mult-mem – The sequence of multicast members in mult-route is shown in mult-mem.

v. pac-num – Total number of packets to be delivered in the current session is denoted by pac-num.

vi. pac-num-delivered – This specifies the number of packets that have already been delivered in the current session.

vii. Alt-route-num – This indicates the number of routes alternative to the current route.

Determination of Link Quality

The quality of a link from n_i to n_j depends on the following factors:-

i. The residual lifetime of n_j

ii. The measure of successful packet delivery capacity per unit time, of the link from n_i to n_j

Residual lifetime rs-$l_j(t)$ of node n_j at time t, is modeled in (1).

$$rs - l_j(t) = (E_j - e_j(t))/edp_j(t) \tag{1}$$

Here E_j and $e_j(t)$ indicate the maximum battery capacity of n_j and consumed energy in the same node by time t. $edp_j(t)$ is the average energy depletion rate of n_j from $(t-\tau)$ to τ. The value of τ is predefined in the network nodes.

Successful packet delivery capacity $sdc_{ij}(t)$ of the link from n_i to n_j at time t, is estimated based on the information maintained in a cache memory termed as comm-history, embedded in router n_i. This cache stores history of communication from n_i to n_j. Attributes of comm-history are as follows:

i. succ-id – This is a unique identifier of the current successor of n_i.

ii. ses-id – This denotes the identifier of the session established from n_i to $n_{succ\text{-}id}$.

iii. init-tms – Timestamp of initiation of session ses-id from n_i to $n_{succ\text{-}id}$, is mentioned in this attribute.

iv. Duration – This field specifies how much time the link from n_i to $n_{succ\text{-}id}$ survived without breakage.

v. pac-num – This is the number of packets successfully delivered from n_i to $n_{succ\text{-}id}$, in the current session ses-id.

vi. trans-num – This attribute specifies the total number transmissions required to deliver pac-num number of packets from n_i to $n_{succ\text{-}id}$. Please note that (trans-num – pac-num) denotes the number of duplicate transmissions or retransmissions to deliver pac-num number of packets in the current session ses-id. The minimum value of (trans-num – pac-num) is zero. Small values of (trans-num – pac-num) indicate an efficient link.

vii. del-pac – Total delay in delivering a pac-num number of packets in session ses-id from n_i to $n_{succ\text{-}id}$ is mentioned in this field.

Let table 1 shows the communication history of n_i.

Table 1. Comm-history of n_i

p	2	10	25	47	49	18
q	1	48	19	27	38	13
u	5	70	30	50	50	20
v	3	134	24	33	47	20
p	3	185	15	18	28	12

Components of successful packet delivery capacity are average transmission success, average duration, and average delay. These are formulated below:

Average Transmission Success (ats)

$$ats_{i,j}(t) = \left(\sum pac - delivered_{i,j}(s)\right) / \left(\sum pac - trans_{i,j}(s)\right) \qquad (2)$$

$s \in S_{i,j}(t) \qquad s \in S_{i,j}(t)$

$S_{i,j}$(t) is the set of communication sessions from n_i to n_j appearing in comm-history of n_i at time t. pac-delivered$_{,j}$(s) is the number of packets that have been successfully delivered from n_i to n_j in session s. pac-trans$_{i,j}$(s) denotes the number of packets that have been transmitted by n_i with an expectation to arrive at n_j. It is quite clear that pac-trans$_{i,j}$(s) ≥ pac-delivered$_{,j}$(s). In a good quality link, very few or no retransmissions are required. So, a high value of average transmission success or ats specifies that most of the transmissions were successful in delivering the data packet to the intended next-hop node. This contributes to increase the efficiency of the link.

Average Duration (adur)

$$adur_{i,j}(t) = \left\{\left(\sum dur_{i,j}(s)\right) / |\, S_{i,j}(t)|\right\} / \mathrm{MAX} dur_{i,p}(s') \qquad (3)$$

$s \in S_{i,j}(t) s' \in S_{i,p}(t)$

np∈succ(i)

The significance of $S_{i,j}$(t) has been described earlier. $dur_{i,j}$(s) is the survival time length of the link from n_i to n_j in session s. If a link has been continuously living for long in the past, then it is expected to survive for long in the current session too.

Average Delay (adel)

$$adel_{i,j}(t) = \left\{\left(\sum delay_{i,j}(s)\right) / |\, S_{i,j}(t)|\right\} / \mathrm{MAX} delay_{i,p}(s') \qquad (4)$$

$s \in S_{i,j}(t) s' \in S_{i,p}(t)$

np∈succ(i)

The meaning of $S_{i,j}$(t) is already explained. Delay$_{,j}$(s) is the delay experienced by packets transmitted by n_i to n_j in session s.

Considering all the factors mentioned above, quality $Q_{i,j}(t)$ of the link from n_i to n_j at time t, is estimated below in (5).

$$Q_{i,j}(t) = \left[\left\{(rs - l_j(t)\, ats_{i,j}(t)\, adur_{i,j}(t))^{1/3}\right\}(1 - adel_{i,j}(t))\right]^{1/2} \tag{5}$$

Please note that compared to adel, residual energy of successor (rs-$l_j(t)$), average transmission success ($ats_{i,j}(t)$), and average duration ($adur_{i,j}(t)$) are given more importance from the perspective of efficiency of a link. FEMS appreciates the fact that delay is tolerable if a link is durable and produces a high packet delivery ratio. It is a basic requirement for a good communication link from n_i to n_j to avoid breakage for a long time and successfully deliver most of the packets transmitted through it. If these packets are delivered fast, then it improves the performance of the link. But delivering only a few packets at the small delay and frequent breakage of links don't help much. Delay is tolerable unless it is very high.

Prioritization of Multicast Packets

Let the multicast queue of n_i consist of the packets pk(1), pk(2), … , pk(u) where $u < M(i)$. M(i) denotes the size of the message queue of n_i. Next, hop downlink neighbor corresponding to pk(u) is denoted as n_u. Route(pk(u)) is the route through which packet pk(u) is supposed to travel. First node of Route(pk(u)) after n_i, is n_u. n_i prioritizes each of its multicast packet based on a fuzzy controller named FUZZ-RANKER. Input parameters of FUZZ-RANKER are as follows:

member-presence

This parameter characterizes each multicast packet depending upon the number of multicast members to be covered by the routes through which each multicast packet is going to travel. It is denoted as $mp_{i,u}(t)$ corresponding to the link from n_i to n_u at time t.

$$mp_{i,u}(t) = [fn1(u,t)(1 - fn2(u,t))]^{1/2} exp\left(1/-1/(f1_{Route(pk(u))}(t) + 1)\right) \tag{6}$$

$$fn1(u,t) = \mathrm{mmbr}_{\mathrm{Route(pk(u))}}(\mathrm{t}) \;/\; \mathrm{init} - \mathrm{rc}_{\mathrm{Route(pk(u))}}(\mathrm{t})$$

$$fn2(u,t) = (1 - \mathrm{mrpc}_{\mathrm{Route(pk(u))}}(\mathrm{t})) \;/\; (1 + \mathrm{init} - \mathrm{rc}_{\mathrm{Route(pk(u))(t))}}$$

$mmbr_{Route(pk(u))}(t)$ is the number of multicast members supposed to receive multicast message through Route(pk(u)) at time t. $mrpc_{Route(pk(u))}(t)$ is the number of multicast member that have already received multicast message. $f1_{Route(pk(u))}(t)$ is the number of alternatives to Route(pk(u)). A route alternative to Route(pk(u)) must comprise of all multicast destinations present in Route(pk(u)). init-$rc_{Route(pk(u))}(t)$ is number of multicast members in the entire route from start(Route(pk(u)) to end(Route(pk(u)), where start(Route(pk(u)) is multicast source n_s and end(Route(pk(u)) is last multicast destination in Route(pk(u)).

The formulation in (6) is based on the heuristics that,

i. if a huge number of multicast members are present in Route(pk(u)), then it means that Route(pk(u)) is going to yield a significant improvement in terms of multicast throughput. If n_i forwards multicast packets to nu very late, then remaining multicast members in Route(pk(u)), that is, $mmbr_{Route(pk(u))}(t)$ number of nodes will face a very high delay. By that time, some of these recipients may not remain alive due to excessive battery exhaustion, making it impossible for them to receive the multicast message. Hence, to get improved network throughput, packets destined to travel through a good number of multicast members are assigned high priority.

ii. It may happen that the multicast source path to n_i was rich in multicast members. This means that already the packet pk(u) has been delivered to a huge number of multicast destinations in Route(pk(u)), and hence, most of the task is done. Therefore, the priority of the packet will decrease.

iii. Importance of Route(pk(u)) increases if multicast recipients covered by Route(pk(u)) are connected to multicast source n_s through only a few alternative routes. The reason is that if the current route breaks and before delivering the packet through an alternative route, some of the multicast destinations present in Route(pk(u)) die due to scarcity of energy, then it will not be possible to deliver multicast packets to them. As a result, the multicast packet delivery ratio will decrease.

It is evident from (6) that member presence lies between 0 and 1. Values close to 1 indicate that the route is rich with a huge number of multicast members, a few of which are predecessors of n_i. This increases the priority of pk(u) to n_i.

Fragility-index

This parameter is based on the concept that if the link from n_i to n_u is fragile, packet pk(u) should be urgently passed by n_i to increase packet delivery ratio and reduce energy consumption. If quality $Q_{i,u}(t)$ of the link from n_i to n_u at time t is not good, then the link will be termed as fragile. The link's importance increases even more if multicast recipients are yet to be covered in Route(pk(u)) and connected to the multicast source through only a few alternative routes. Fragility index $fra\text{-}indx_{i,u}(t)$ of the link from ni to nu at time t, is mathematically modeled as,

$$fra - indx_{i,u}(t) = \left(1 - Q_{i,u}(t)\right) exp\left(1 - 1/(f1_{oute(pk(u))}R(t) + 1)\right) \quad (7)$$

This parameter of FUZZ-RANKER also lies between 0 and 1. Values close to one denote that the link from n_i to n_u is fragile; its quality is not good. Hence, n_i increases the priority of pk(u) to forward it as early as possible.

Delay-index

Routers give priority to the packets that have already suffered a huge amount of delay. Time-to-Live or TTL is the maximum life span of a data packet. If a data packet pk(u) has experienced great delay (very close to TTL) in reaching current router n_i from multicast source n_s then n_i might have to drop the packet if it assigns a low priority to pk(u), that is, choose to process it very late. The packet may no longer remain alive (summation of waiting time in all routers from n_s to (and including) n_i, is greater than TTL) by the time n_i decides to forward the packet. This increases the number of transmissions (and retransmissions in certain cases) and leads to complete wastage of energy from n_s to all outers till n_i. The situation compels n_s to ask its zonal controller about an alternative route to multicast destinations mentioned in Route(pk(u)). If some of these destinations die out of heavy battery power depletion, then the percentage of successful data packet delivery will substantially reduce. Delay index dl-indx$_{i,u}$(t) of the link from n_i to n_u at time t, is formulated (8).

$$dl - indx_{i,u}(t) = \Big[\sum w(pk(u), v)\ ]\ /TTL\Big] \qquad (8)$$

$v = 1$

w(pk(u), v) is the waiting time faced by packet pk(u) in router n_v. Since overall waiting time, the summation of delay in all routers cannot be greater than TTL, so, dl-indx$_{i,u}$(t) also lies between 0 and 1. This parameter's high values denote that the packet has suffered a huge delay and should get some relief now being processed faster in the current router.

Rule bases of Fuzz-Ranker combine the above-defined parameters in tables 3 and 4. In contrast, table 2 demonstrates the division of these parameters in crisp ranges and corresponding fuzzy premise variables L, S, H, and VH.

Table 2. Crisp range division of Fuzz-Ranker

Range division of all parameters	Fuzzy Variable
0-0.25	L
0.25-0.5	S
0.5-0.75	H
0.75-1.0	VH

Rule bases of Fuzz-Ranker appear in tables 3 and 4. Table 3 combines member-presence or mp and fragility index or fra-indx. Both of these parameters have equal weight because both are essential components of the priority of a packet. If t1 is high, then many multicast members are dependent on the router, and the route is not that stable. Therefore, if the route breaks, then the link to all those destinations will be lost, and alternative route information needs to be asked. There is no guarantee that the alternative route will cover all those multicast destinations. Hence a collection of alternative routes might have to be discovered and maintained, leading to additional message cost and energy consumption. It is more destructive for the network if packets traveling through a route connecting many multicast destinations suffer from more delay than those traveling towards a single multicast destination. t1 is combined with dl-indx in table 4. The priority of a fragile route with a huge number of multicast members increases if it suffered a high delay during its journey from the multicast source to the current router.

Table 3. Composition of mp and fra-indx is t1

mp **fra-indx**	**L**	**S**	**H**	**VH**
L	L	L	L	L
S	L	S	S	S
H	L	S	H	H
VH	L	S	H	VH

Table 4. Combination of t1 and dl-indx producing priority

t1 **dl-indx**	**L**	**S**	**H**	**VH**
L	L	S	H	VH
S	L	S	H	VH
H	L	S	H	VH
VH	S	H	VH	VH

Simulation Experiments

Simulation Environment

This experiment is based on SDN and the IEEE 802.15.4 protocol for wireless sensor networks. The network emulator for the framework is Mininet [30], and the controller is Floodlight [31]. Floodlight runs on a server with an AMD Opteron processor 6348 and 16 GB memory. The server is installed with Linux kernel version 2.6.32. Mininet runs on a separate server, and a 10 Gbps Ethernet network connects the servers.

Table 5. Simulation Parameters

Network parameters	Values
Number of nodes	50, 75, 100, 125, 150, 180
Network area	500 m × 500 m
Radio range	10 m – 40 m
Initial energy of nodes	10 j – 20 j
Size of each packet	512 bytes

Simulation metrics are,

i) Message Cost (MC) - This is the summation of all node messages in the network. If msg_k denotes the total number of messages sent by n_k throughout the simulation period, then message cost MC is formulated below:

$$MC = \sum msg_k$$

$$n_k \in NW$$

ii) Energy Consumed (EC) – This is the summation of energy consumed in all network nodes. It is mathematically formulated below.

$$EC = \sum (m - r - en_k)$$

$$n_k \in NW$$

iii) Network Throughput (NT) – This is the percentage of data packets that were successfully delivered to their respective destinations. t-p is the number of packets transmitted throughout the communication session. d-p is the number of packets successfully delivered to their destinations throughout the simulation run.

$$NT = (d - p/t - p) \times 100$$

iv) Average Delay (AD) – This is a summation of delay faced by all packets in the network, divided by the number of packets transmitted. PAC is the set of all packets transmitted throughout the simulation. d-l(pac) denotes the delay suffered by packet pac.

$$AD = \sum d - 1(pac)/\,|PAC| \qquad pac \in PAC$$

Simulation Results and Discussion

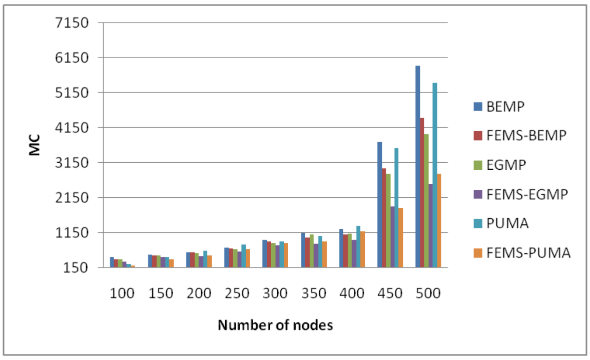


Figure 6. MC vs. the number of nodes

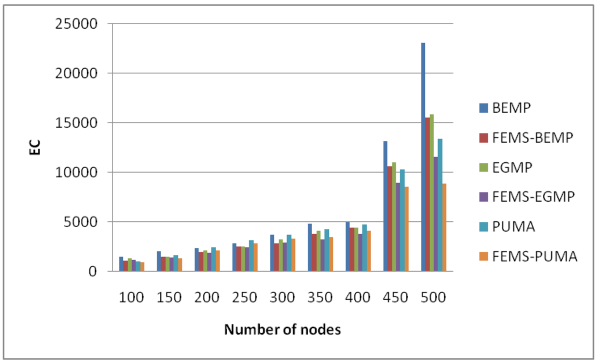


Figure 7. EC vs. the number of nodes

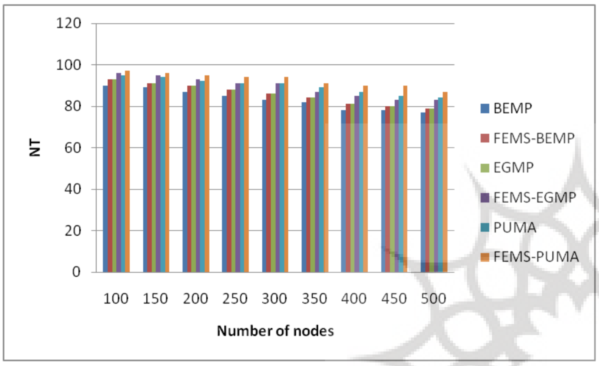


Figure 8. NT vs. the number of nodes

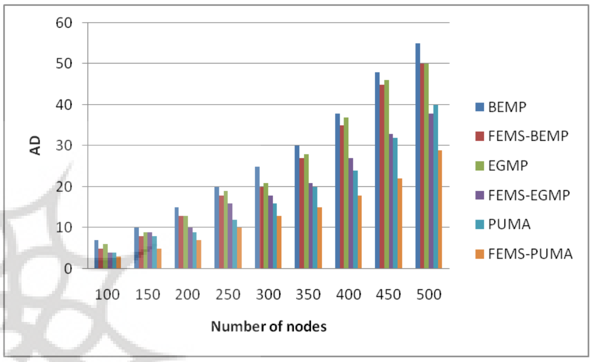


Figure 9. AD vs. the number of nodes

Ethnic BEMP vs. FEMS-BEMP

FEMS is a scheduling protocol that prioritizes multicast packets waiting in the multicast queue of a node and forwards packets in decreasing order of priority. It does not interfere with the underlying multicast protocol. Hence, the packet with the highest priority is processed first. BEMP is a multicast protocol that constructs a multicast tree depending upon the residual energy of nodes. Packets are scheduled on a First-come-First-served or FCFS basis. FEMS-BEMP follows the same routing protocol BEMP couples with FEMS scheduler. FEMS considers two additional aspects of energy efficiency, like a residual lifetime and successful packet delivery capacity of a link. The main importance of residual lifetime compared to residual energy is that a node with very high residual energy may exhaust faster due to a high energy depletion rate compared to another node with comparatively low residual energy and smaller energy depletion rate. Successful packet delivery capacity of a link I measured as per the history of communication through that link. Components of successful packet delivery capacity are average transmission success, duration, and delay. If a link survived for a long time in earlier sessions and delivered, most packets transmitted or forwarded through this, without much delay. FEMS names these links as efficient links. Multicast packets destined to travel through inefficient links and about to be delivered to more than one multicast member in the same route are given higher priority in FEMS than those traveling through efficient links that belong to routes consisting of only one or very few numbers of multicast members. This improves the packet delivery ratio and saves message costs and restructuring a multicast tree by repairing broken links. Saving of message cost yields a reduction in energy consumption as supported by figures 6, 7, 8, and 9 in favor of FEMS-BEMP.

Ethnic EGMP vs. FEMS-EGMP

EGMP treats multicast as a geocast operation where an area is defined containing all multicast members. But it may include non-members as well, leading to a lot of unnecessary transmission cost, energy consumption, and delay. When FEMS couple with EGMP, it teaches the flavor of significantly strong additional energy efficiency through the fuzzy controller FUZZ-RANKER that evaluates the quality of a link in the history of packet delivery the average time required to transmit each of them. If the number of retransmissions required to deliver a packet through one particular link is high, it contributes to the link's inefficiency. FEMS gives priority to multicast packets traveling through inefficient links and destined to be delivered to a lot of members through a single route. Hence, the number of retransmissions reduces, yielding smaller message cost and delay in FEMS-EGMP than the ethnic version of EGMP.

Ethnic PUMA vs. FEMS-PUMA

In PUMA, each multicast member of a group participates in the election of a core that receives a multicast message from source and propagates the same to all members. When a fuzzy controller assists PUMA, FEMS message cost reduces up to a great extent. FEMS utilizes route information in packets and identifies two components of the urgency of a message named fragility and delay. Suppose a packet is to travel through a fragile link (fragility is decided based on communication history). In that case, it must be forwarded fast to improve the packet delivery ratio and message cost, as shown in figures 6, 7, 8, and 9.

Conclusion

This article proposes a scheduler exclusively for multicast packets. The author is confident that it is a novel work. The fuzzy controller can be applied with any multicast routing protocol. It assigns priority to packets that will travel through fragile and inefficient routes. This technique greatly reduces energy consumption in the network, increasing its throughput.

Declaration

Availability of data and materials

The author has filed a patent application and doesn't want to disclose the data before the patent is granted.

Competing interests

There are no competing interests as far as this paper is concerned.

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Authors contribution

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