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Research Article

Cross-layer Based Routing and Power Aware Rate Adjustment (CBR-PARA) MAC Protocol for MANET

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Abstract: MANETs are capable of forming wireless network that can setup a transmission range between the nodes in the network. In this study we propose an efficient power and rate control scheme MAC layer. Also in this approach the best path will be selected by considering the residual energy of node. Here we extend the process of selecting the path by also considering the path's residual energy of the node. This residual energy is estimated at both the situations when the node receives data packets and transmits the data packets. Also we have proposed a method where each node updates a table. This table includes energy efficiency in all combinations of transmission power and rate.

Keywords: Bluetooth networks, mobile ad-hoc network, stable topology, wireless mobile nodes

INTRODUCTION

Mobile Ad-hoc Network (MANET): Mobile Ad-hoc Network (MANET) is a set of wireless mobile nodes which are infrastructure-less network consisting of numbers of mobile hosts communicating with one another via relaying messages among mobile hosts through multi hop wireless links. These MANETs are capable of forming wireless network that can setup a transmission range between the nodes in the network. The mobile nodes of MANET can join and leave or change their position anytime inside the network. In such kind of situation it may be crucial for one node to enroll other hosts in forwarding a packet to its destination due to the limited transmission range of wireless network interfaces. Every single node in the network may not be in direct transmission range of with other nodes and each node in the network operates not only as a host but also as router by forwarding packets to other mobile nodes in the network. In addition to the routing protocols in MANETs have to cope with problems like the exposed and hidden terminal problem or the usage of a shared medium, which can lead to frame collisions. Examples for mobile ad-hoc networks are ZigBee and Bluetooth networks.

The most main feature of the MANETs is the lack of a fixed infrastructure. None of the network is to support individually or specific network functionality, with routing topology discovery and data forwarding being the most prominent example. Additional examples of functions that cannot rely on a central service and which are also of high relevance to this study, are naming services, Certification Authorities (CA), directory and other administrative services. Designing a routing protocol for mobile ad hoc networks depends on various factors like mobility, resource constraint, bandwidth, hidden and exposed terminal problems etc. Thus, routing protocol is structured for purposes such as fully distributed, adaptive frequent and stable topology, loop free and minimum number of collisions (Liu *et al*., 2004; Jain *et al*., 2009; Rajaram and Palaniswami, 2010).

Efficient transmission rate assignment: As the effective approach to realize energy efficient data transmission, transmission power control and transmission rate control are presented. MAC protocols with transmission power control are derived from IEEE 802.11 DCF. Data are transmitted with required minimum transmission power to improve energy efficiency of data transmission. The required minimum received power is calculated according to measurement of received power of control frames. MAC protocols with transmission rate control are used in ad hoc networks with multi-rate physical layer such as IEEE 802.11b. In these protocols, data are transmitted in a high data transmission rate to shorten data transmission time. Therefore, the energy consumption efficiency of data transmission can improve (Zhai *et al*., 2005; Bandai *et al*., 2008).

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Objectives: In a mobile network, the nodes have to know their transmission rate in order to maintain a certain discipline during the transmission of data packets between the nodes. If there is no proper transmission rate approach then the network faces packet loss since TCP congestion control has an implicit assumption, which is that any packet loss is due to network congestion. So in order to overcome this drawback it is important to have an approach which deals with the transmission rate in the network.

In this study we have developed a cross-layer based routing protocol with power and rate adjustment. We propose a proper method where each node updates the power and rate table. This table includes energy efficiency in all combinations of transmission power and rate.

LITERATURE REVIEW

Bandai *et al*. (2008) have proposed a Medium Access Control (MAC) protocol with transmission power and transmission rate control in multi-rate ad hoc networks. This protocol realizes high energy efficient data transmission. In this proposed protocol, each node prepares a table that includes energy efficiency in all combinations of transmission power and rate. By exchanging of control frames and looking up the transmission power and rate table, direct and relay transmission sequences are used arbitrarily. When relay transmission by intermediate node between sender and receiver is more effective in terms of power consumption, relay sequence is adopted instead of direct transmission. The advantage of this proposed approach is that it can realize high energy efficient data transmission via computer simulations.

Zhang *et al*. (2008) have proposed a practical SNR Guided Rate Adaptation (SGRA) scheme. Based on these observations, The SNR measures in hardware are often uncelebrated and thus the SNR thresholds are hardware dependent. The direct prediction from SNR to Frame Delivery Ratio (FDR) is often over optimistic under interference conditions. The authors have also conducted a systematic measurement-based study to confirm that in general SNR is a good prediction tool for channel quality. The advantage of this approach is that it helps the network to achieve max throughput.

Zhai *et al*. (2007) have proposed a new Wireless Congestion Control Protocol (WCCP) to efficiently and fairly support the transport service in multi hop ad hoc networks. In this protocol, each forwarding node along a traffic flow exercises the inter-node and intra-node fair resource allocation and determines the MAC layer feedback accordingly. The end-to-end feedback, which is ultimately determined by the bottleneck node along the flow, is carried back to the source to control its sending rate. The advantage of this approach is that WCCP significantly outperforms traditional TCP in terms of channel utilization, delay and fairness and eliminates the starvation problem.

Rahman and Hasan (2010) have proposed a novel Explicit Rate-based Congestion Control mechanism (XRCC), for supporting applications like multimedia streaming over MANET. This approach minimizes packet drops caused by network congestion as compared to TCP congestion control mechanism; it still suffers from packet drops. Also the rate feedback can be made more accurate by considering the available network bandwidth. The advantage of this approach is that XRCC mechanism outperforms TCP congestion control mechanism and thus is well suited for applications like multimedia streaming in MANET.

Ping *et al*. (2006) have proposed a new multipath routing protocol, MEER (Multipath Energy-Efficient Routing). This approach is based on the SMR (Split Multipath Routing) protocol that maintains the advantages of on-demand protocols while providing energy efficiency. It does not only protect the nodes from overly consuming the energy compared to the other nodes in the network, but also prolongs the lifetime of the network. The advantage of this approach is that it can improve the mean time to node failure and balance the load in ad hoc networks.

Santhi and Sadasivam (2011) have proposed a new protocol Power Aware QoS Multipath Routing protocol (PAQMR) for disaster recovery network. This protocol is the enhanced protocol of Ad-hoc on Demand Multipath Distance Vector protocol (AOMDV). This routing protocol is used to avoid the loop formation in network so that it reduces congestion in the channel. The metrics for the simulation is energy consumption, average end to end delay and packet delivery ratio by varying the traffic load and pause time in the network. The advantage of this approach is that this proposed protocol minimizes the power, delay, congestion and maximize the packet delivery ratio.

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PROPOSED METHODOLOGY

Overview and system design: Our previous work, Narayanan and Thottungal (2013) comprises of two fuzzy systems namely Fuzzy Logic System 1 (FLS1) and Fuzzy Logic System 2 (FLS2). The former is responsible for best path selection and later is responsible for rate adjustment. In FLS1, the source obtains the input parameters such as path stability and bandwidth through route discovery mechanism. These inputs are fuzzified to obtain the optimal path for data transmission. In FLS2, the destination node takes end-to end delay and packet loss ratio values as inputs. These inputs are fuzzified to estimate the state of transmission rate. By comparing the initial transmission rate of path with output of FLS2, the current transmission rate of the path is adjusted.

In this study we have extended the process of selecting the path by also considering the path's residual energy of the node. This residual energy is estimated in this study. This residual energy is considered in the algorithm while selecting the path. Also we propose a proper method where each node updates the power and rate table. This table includes energy efficiency in all combinations of transmission power and rate.

System design: Figure 1 shows block diagram our approach. First the residual energy will be calculated and then this residual energy is considered in the path selection. Next, each node will update the transmission table with power and rate factors.

Fuzzy based optimum path selection:
Estimation of residual energy: Energy consumption of a node after time t is calculated by using the below equation:

$$E_{con}(t) = N_t * C_1 * N_r * C_2 \quad (1)$$

where,

$E_{con}(t)$ = The energy consumed by a node after time t
N_t = The number of packets transmitted by the node after time t
N_r = The number of packets received by the node after time t
C_1, C_2 = Constant factors having a value between 0 and 1

The residual energy E_{Res} of a node at time t, is calculated by using the formula:

$$E_{Res} = E - E_{con}(t) \quad (2)$$

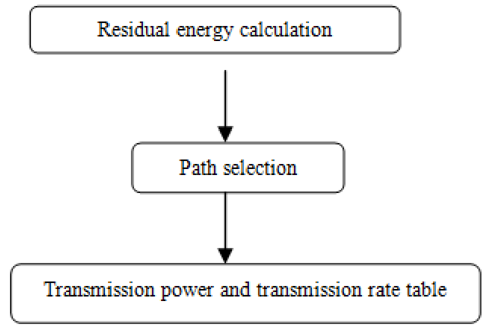

Fig. 1: Block diagram of our approach

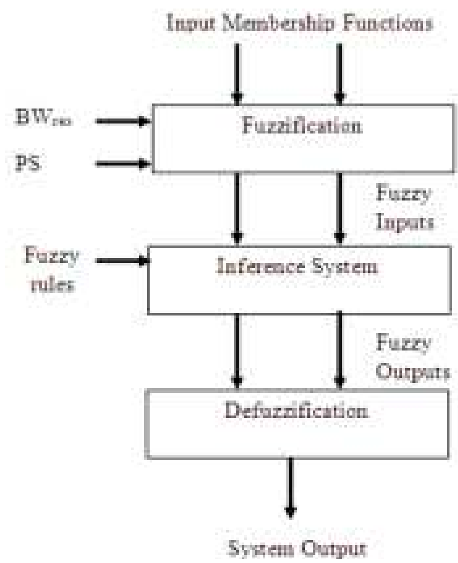

Fig. 2: Fuzzy Logic System (FLS1)

where, E is the initial energy of a node.

This residual energy is used in the path selection process.

Fuzzy Logic System 1 (FLS1): Figure 2 demonstrates the Fuzzy Logic System (FLS1) that involves the selection of optimal path for data transmission. This is performed by considering the three inputs such the path stability, residual bandwidth and residual energy. The stability and residual bandwidth are estimated using Narayanan and Thottungal (2013). These inputs are fuzzified to obtain the appropriate optimal path.

The steps that determine the fuzzy logic system are as follows.

Fuzzification: The process of getting the crisp inputs from the chosen input variables and estimating the degree to which the inputs belong to each of the appropriate fuzzy sets are termed as fuzzification.

Inference system: In this step, the fuzzified inputs are taken and applied to the antecedents of the fuzzy rules. It is then applied to the consequent membership function. Finally the outputs of all rules are merged.

Table 1: Fuzzy rules

S. No.	BW_{res}	PS	E_{Res}	OP
1.	Low	Low	Low	Very low
2.	Low	Medium	Low	Low
3.	Low	High	Low	Low
4.	Low	High	High	High
5.	Low	Medium	Medium	Medium
6.	Low	High	Medium	Medium
7.	Medium	Low	Low	Low
8.	Medium	Medium	Medium	Medium
9.	Medium	High	Medium	Medium
10.	Medium	High	High	High
11.	High	Low	Low	Low
12.	High	Medium	Medium	Medium
13.	High	High	Medium	High
14.	High	Medium	High	High
15.	High	High	High	Very high

Defuzzification: In this step, the merged output of the aggregate output fuzzy set is taken as input and a single crisp number is obtained as output.

Fuzzification: This involves fuzzification of input variables such as PS, BW_{res} and E_{Res}. The crisp inputs are taken from these variables and these inputs are given a degree to appropriate fuzzy sets. The crisp inputs are combination of PS, BW_{res} and E_{Res}. We take five possibilities Very high, high, medium, low and very low for the output.

In Table 1, BW_{res}, PS and E_{Res} are given as inputs and the output represents the Optimal Path (OP) for data transmission. Then 15 fuzzy rules are defined with the combinations presented in Table 1.

Table 1 demonstrates the designed fuzzy inference system. This illustrates the function of the inference engine and method by which the outputs of each rule are combined to generate the fuzzy decision.

For example, let us consider Rule 15.

If BW is high and PS is high and E_{Res} is high, then
The choice of optimal path is very high.
Similarly in Rule 1
If BW is low and PS is low and E_{Res} is low, then
The choice of optimal path is very low

Defuzzification: The technique by which a crisp values is extracted from a fuzzy set as a representation value is referred to as defuzzification. The centroid of area scheme is taken into consideration for defuzzification during fuzzy decision making process. The Eq. (5) describes the defuzzifier method:

$$\text{Fuzzy\_cost} = [\textstyle\sum_{allrules} z_i * \lambda(z_i)] / [\textstyle\sum_{allrules} \lambda(z_i)] \quad (3)$$

where, fuzzy_cost is used to specify the degree of decision making, z_i is the fuzzy all rules and variable and λ (z_i) is its membership function. The output of the fuzzy cost function is modified to crisp value as per this defuzzification method.

Algorithm for optimal path selection: The steps involved in the optimal path selection are as follows:

- When S wants to transmit a data packet to D, it verifies its route cache for path availability:

```
If path exists
    Then
        Goto step 10
    Else
        Goto Step 2
End if
```

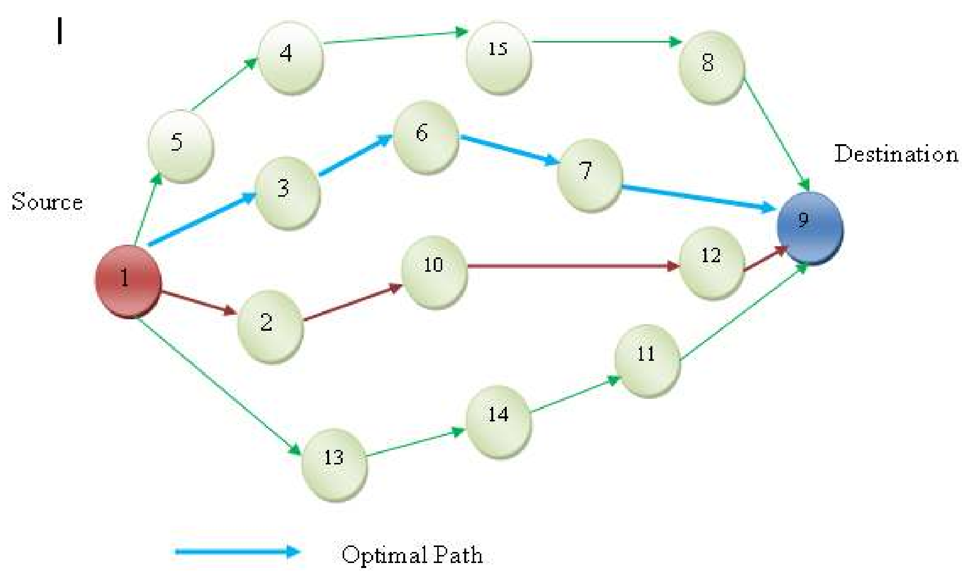

Fig. 3: Optimal path selection

Table 2: Transmission power and rate table

I	j	Power P_i dBm	Rate R_j Mb/sec	Req. Rx pow. gap Δ (P_i, R_j) dBm	Pow. cons. ratio ρ (P_i, R_j)
0	0	14.77	1.0	0.00	1.000
1	0	13.01	1.0	1.78	0.844
0	1	14.77	2.0	3.00	0.508
1	1	13.01	2.0	4.76	0.429
0	2	14.77	5.5	5.00	0.195
1	2	13.01	5.5	6.76	0.164
2	2	6.99	1.0	7.78	0.611
0	3	14.77	11.0	9.00	0.105
1	3	13.01	11.0	10.76	0.089
:	:	:	:	:	:
3	3	0.00	11.0	23.77	0.058

- S broadcasts RREQ packet towards the D through the intermediate nodes (N_i):

$$S \xrightarrow{*RREQ} N_i \xrightarrow{*RREQ} D$$

- N_i upon receiving the RREQ updates the route cache by using the Table 1 of previous work.
- N_i then either re-broadcasts the RREQ to its neighbours or sends the Route Reply (RREP) if the node is D. This process is repeated till RREQ reaches D.
- When D receives RREQ, for every received RREQ the RREP packet is unicast in the reverse path towards the source.
- Every N_i that receives RREP updates its cache for the next-hop of the RREP and then unicasts this RREP in the reverse-path using the earlier-stored previous-hop node information.
- Step 6 is repeated till RREP reaches S.
- S then estimates the path stability and bandwidth as per Narayanan and Thottungal (2013). It also estimates the residual energy given by Eq. (2).
- The values computed by S in step 8 are considered as inputs for fuzzy logic system. Based on the result, S selects an optimal path that has high link stability, bandwidth value and residual energy as described in Fuzzy Logic System 1 (FLS1) this optimal path is used for data transmission between the source and the destination.
- The path available in the route cache is considered for data transmission.

Figure 3 shows the optimal path selection technique. The path (S-3-6-7-D) is the best path chosen (Fuzzy state-very high) for data transmission. The path (S-2-10-12-D) is next level optimal path (Fuzzy state-high) for data transmission.

Estimation initial transmission power and physical data rate: In this section, for estimating the initial physical date rate, the transmission power level and power consumption ratio is considered.

This table includes the energy efficiency of all combinations of transmission power and transmission rate. Table 2 consists of many columns like Power (P), Rate (R), power gap (*Δ*), energy ratio (ρ). In this approach the number of neighbour nodes, (Request-to-Send) RTS collision probability and bit error rate has to be obtained very carefully. By using the specification of the network card, the transmission power and rate table of the proposed protocol is prepared. Hence there is no need to calculate any parameters about network topology, traffic pattern and radio propagation.

Let,

$$P_0, P_1, P_2, \ldots, P_{n-1} (P_0 > P_1 > \cdots > P_{n-1})$$

dBm be the n levels of transmission power available. The maximum transmission power P_0 is defined as base transmission power. Let m be the levels of data rate available which are $R_0, R_1, \ldots, R_{m-1} (R_0 < R_1 < \cdots < R_{m-1})$ Mbps. The lowest data rate R_0 is defined as base transmission rate. The energy efficiency ratio $\rho\ (P_i, R_j)$ as follows:

$$\rho\ (P_i, R_j) = \frac{E(P_i, R_j)}{E(P_0, R_0)} \tag{4}$$

Here $E\ (P_i, R_j)$ is the energy consumption when transmission power P_i and rate R_j are adapted.

The required power gap to receive a data $\Delta\ (P_i, R_j)$ dBm is defined as given below:

$$\Delta\ (P_i, R_j) = \pi\ (P_i, R_j) - \pi\ (P_0, R_0) \tag{5}$$

Here $\pi\ (P_i, R_j)$ dBm is the required power to receive a data. $\rho\ (P_i, R_j)$ and $\Delta\ (P_i, R_j)$ are calculated by the specification of network card. The transmission power and rate table for Cisco Aironet 350 is as given in the Table 1. The card has four level of transmission power like $P_0 = 14.77$, $P_1 = 13.01, P_2 = 6.99$ and $P_3 = 0$ dBm. And also four levels of transmission rate which are $R_0 = 1$, $R_1 = 2$, $R_2 = 5.5$ and $R_3 = 11$ Mb/sec. in table there are 16 combinations of transmission power and rate. Example: if $P_0 = 14.77\ dBm$ and $R_3 = 11$ Mb/sec are selected then the energy consumption is 0.105 times as that of the base transmission power and rate. The required power at a receiver is 9.00 dBm larger than that of base transmission power and rate. The node will calculate

Table 3: Fuzzy rules for FLS2

S. No.	DE-E	PLR	OP
1.	Low	Low	Very high
2.	Low	Medium	High
3.	Low	High	Low
4.	Medium	Low	Medium
5.	Medium	Medium	Medium
6.	Medium	High	Low
7.	High	Low	Low
8.	High	Medium	Low
9.	High	High	Very low

the received power when the node receives a control frame such as RTS.

Let p dBm be the received power of the RTS.

The power gap is given by p – $\pi\ (P_0, R_0)$, hence the combination satisfying $\Delta\ (P_i, R_j) <$ p – $\pi\ (P_0, R_0)$ is selected from the table.

Fuzzy based transmission rate adjustment: The source proceeds with the transmission of data to the destination with the initial transmission rate estimated from Table 2, through the selected optimal path (Described in section Algorithm for Optimal Path Selection). At this moment, at the receiver side, the destination node computes the parameters such as End-To-End Delay (DE-E) and Packet Loss Ratio (PLR) as explained in Zhang *et al*. (2008). It then applies these inputs to Fuzzy Logic System (FLS2) in order to estimate the state of transmission Rate (Rtx).

Fuzzification: This involves fuzzification of input variables such as $D_{E\text{-}E}$ and PLR. The crisp inputs are taken from these variables and these inputs are given a degree to appropriate fuzzy sets. The crisp inputs are combination of $D_{E\text{-}E}$ (say D) and PLR (say L). We take five possibilities, for output such as very high, high, medium, low and very low.

In Table 3, DE-E and PLR are given as inputs and the output represents the transmission Rate (Rtx). The 9 fuzzy rules are defined with the combinations presented in Table 3.

Let us consider Rule 1:

If DE-E is low and PLR is low, then
The state of transmission rate of the source is Very high
Similarly,
If DE-E is high and PLR is high, then
The state of transmission rate of the source is very low

The obtained output value is defuzzified. As an outcome of fuzzy decision, we can obtain the state of transmission rate. The current transmission rate of the source is adjusted by comparing the output of FLS2 with initial transmission rate of path.

The physical data rate of the source is adjusted by referring the transmission power and rate table (Table 2) by suitably choosing the data rate and power combinations according to Table 3 (Explained in section estimation initial transmission power and physical data rate).

Advantages: The advantage of this approach is that the selected path in the network by the source node will be more stable and more energy efficient, since the source node considers the residual energy of the nodes that lies between the source and destination node. Also through this way the network's and node's lifetime will be prolonged.

SIMULATION RESULTS

Simulation model and parameters: The Network Simulator (NS2) (Zhang *et al*., 2008), is used to simulate the proposed architecture. In the simulation, 150 mobile nodes move in a 1000×1000 m region for 50 sec of simulation time. All nodes have the same transmission range of 250 m. The simulated traffic is Constant Bit Rate (CBR).

The simulation settings and parameters are summarized in Table 4.

Performance metrics: The proposed Cross-layer Based Routing and Power Aware Rate Adjustment (CBR-PARA) Technique is compared with the EE-MAC technique (Bandai *et al*., 2008). The performance is evaluated mainly, according to the following metrics.

Packet delivery ratio: It is the ratio between the number of packets received and the number of packets sent.

Packet drop: It refers the average number of packets dropped during the transmission.

Residual energy: It is the amount of energy which was remains in the participant nodes.

Results:

Based on rate: In our first experiment we vary the transmission rate as 100, 200, 300, 400 and 500 Kb, respectively.

Figure 4 shows the delivery ratio of CBRPARA and EEMAC techniques for different rate scenario. We can conclude that the delivery ratio of our proposed CBRPARA approach has 27% of higher than EEMAC approach.

Figure 5 shows the packet drop of CBRPARA and EEMAC techniques for different rate scenario. We can conclude that the drop of our proposed CBRPARA approach has 11% of less than EEMAC approach.

Figure 6 shows the residual energy of CBRPARA and EEMAC techniques for different rate scenario. We can conclude that the residual energy of our proposed CBRPARA approach has 2% of higher than EEMAC approach.

Based on flows: In our second experiment we vary the number of flows as 2, 4, 6, 8 and 10, respectively.

Table 4: Results of simulation settings and parameters

No. of nodes	150
Area size	1000×1000
Mac	IEEE 802.11
Transmission range	250 m
Simulation time	50 sec
Traffic source	CBR
Packet size	512
Sources	2,4,6,8 and 10
Rate	100, 200, 300, 400 and 500 kb
Initial energy	9.1J
Transmission power	0.660
Receiving power	0.395

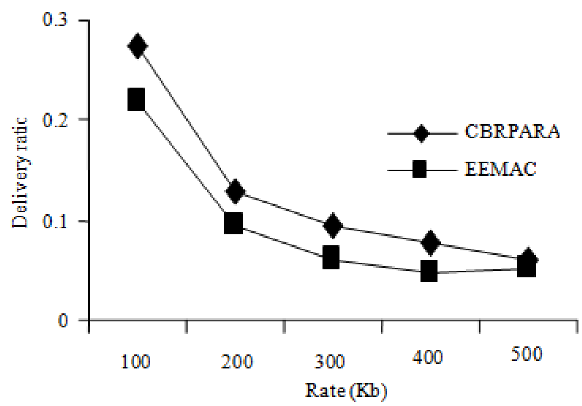

Fig. 4: Rate vs. delivery ratio

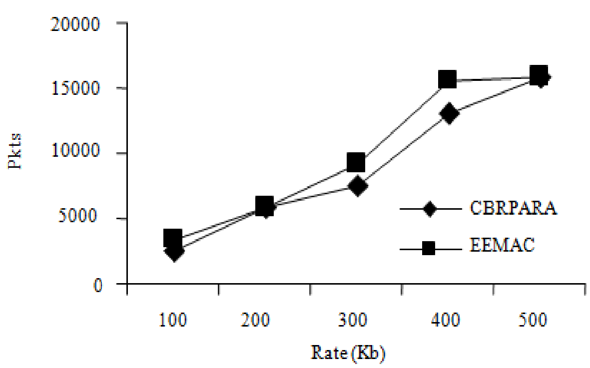

Fig. 5: Rate vs. drop

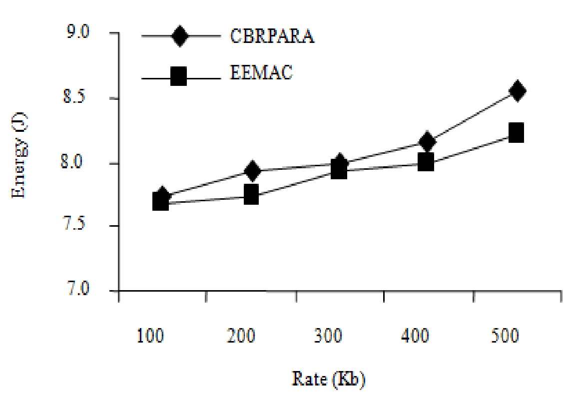

Fig. 6: Rate vs. residual energy

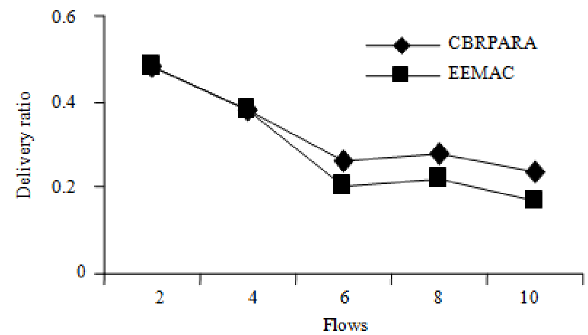

Fig. 7: Flows vs. delivery ratio

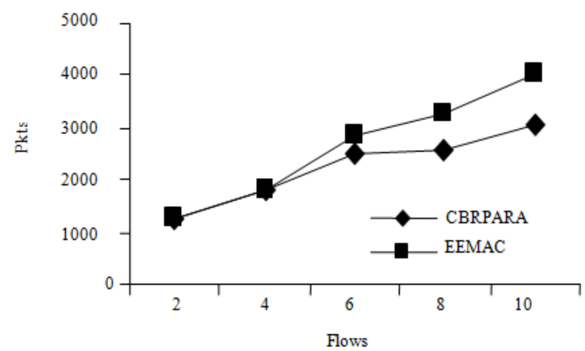

Fig. 8: Flows vs. drop

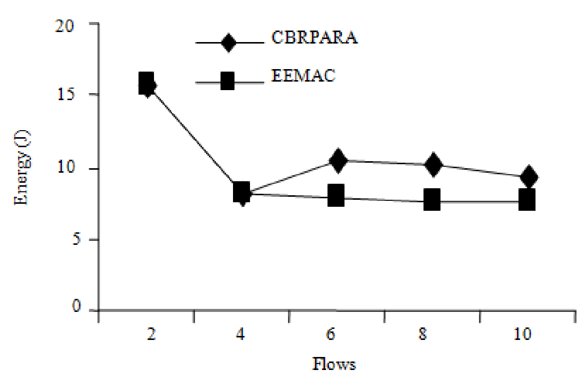

Fig. 9: Flows vs. residual energy

Figure 7 shows the delivery ratio of CBRPARA and EEMAC techniques for different rate scenario. We can conclude that the delivery ratio of our proposed CBRPARA approach has 15% of higher than EEMAC approach.

Figure 8 shows the packet drop of CBRPARA and EEMAC techniques for different rate scenario. We can conclude that the drop of our proposed CBRPARA approach has 11% of less than EEMAC approach.

Figure 9 shows the residual energy of CBRPARA and EEMAC techniques for different rate scenario. We can conclude that the residual energy of our proposed CBRPARA approach has 14% of higher than EEMAC approach.

CONCLUSION

In this extension study, we have proposed an efficient power and rate control scheme MAC layer. Also in this approach the best path will be selected by considering the residual energy of node. Here we have extended the process of selecting the path by also considering the path's residual energy of the node. This residual energy is estimated at both the situations when the node receives data packets and transmits the data packets. Also we have proposed a method where each node updates a table. This table includes energy efficiency in all combinations of transmission power and rate.

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