Asian Journal of Information Technology 15 (8): 1396-1404, 2016
ISSN: 1682-3915

Energy-Efficient Wireless Network Communication with Priority Packet Based QoS Scheduling

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Abstract: Wireless networks have become increasingly popular due to their wide range of applications. Energy consumption is one of the biggest constraints of the wireless node and these limitations combined with a typical deployment of large number of nodes have added many challenges to the design and management of wireless networks. Energy efficiency is an important issue for mobile computers since they must rely on their batteries. QoS (Quality of Service) in sensor application plays a very important role. QoS based routing is required to ensure the best use of nodes in Wireless networks. In this paper, we propose a PRIMA protocol is the best performance in the category of Packet Prioritization, Scheduling Scheme, Queue Type, Energy Awareness and QoS. PRIMA is a QoS based routing in Medium Access Control (MAC) protocol for wireless multimedia traffic.

Key words: Quality of service, media access control, PRIMA, wireless network, consumption

INTRODUCTION

The energy consumption of portable computers like PDAs and laptops is a limiting factor in the amount of functionality that can be placed in these devices. The wireless network interface of a mobile computer consumes a significant fraction of the total energy consumed by a mobile computer. More extensive and continuous use of network services will aggravate this problem. Energy efficiency can be improved at various layers of the communication protocol stack. However, even today, research is still focused on performance and (low power) circuit design. There has been substantial research in the hardware aspects of mobile communications energy efficiency (Francomme *et al*., 2006) such as low-power electronics, power-down modes and energy efficient modulation. Due to fundamental physical limitations though, progress towards further energy-efficiency (Francomme *et al*., 2006; Othman *et al*., 2011) will become mostly an architectural and software-level issue.

Wireless Sensor Network (WSN) is a wireless network consisting of small sensing nodes, which have computation and communication capabilities, operates in an unattended environment (Akyldiz *et al*., 1999; Akyildiz *et al*., 2002). WSN routes data back to Base Station (BS) based on the priority based service of the MAC protocols. Data transmission processes from node to node or Multi hop towards the BS or gateway. A wide variety of applications (Havinga and Smit, 2000; Havinga *et al*., 2000) could be supported by deploying WSNs in many different situations, whether they are composed of mobile or stationary nodes. Considering the dynamic nature of the network, several new protocols have been proposed that are more concern about QoS (Chen *et al*., 1998; Choi and Shin, 1998).

In Wireless networks, there are two types of protocols used to carry out the communication process between the nodes; they are Routing protocols and Mediam Access Control (MAC) protocols. The basic communication type considers send periodic data or event-driven data to the base station or to the sink. The node extracts data from a particular location and then multicast or broadcast of data is needed. Routing protocols (Villalba *et al*., 2009) needed to fulfill these requirements along with energy conservation and QoS factors. The MAC protocol also plays an important role in accessing the channels using sensor nodes and maintains energy saving, throughput, QoS and minimum delay. However, these protocols can be grouped based on problems they solve, like prioritization: differentiate services based on definition of class of traffic, Timeliness: Guaranteed delivery within a given time, Reliability: Ensuring probability of delivery etc. (Choi and Shin, 1998). Many MAC layer protocols were proposed for WSN. Some of them are contention based like, T-MAC (Colombo *et al*., 1999), S-MAC (Havinga and Smit, 2000); some are QoS based such as Q-MAC (Havinga *et al*., 2000) and along with that many QoS based routing protocol have been proposed like, SAR SPEED (Moorman and Lockwood, 1999).

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Luiterature review: Havinga and Smit (2000) presented a MAC scheduling principle for a TDMA system that reduces significantly the energy consumption that is needed for the mobile to communicate, albeit not providing the most efficient bandwidth utilization. The scheduling principle (called mobile grouping) is based on a reordering of the transmission frame such that mobiles can operate in a low power operating state as long as possible. Joint power and rate control with QoS constraints have been studied extensively for multiple-access networks by Honig and Kim (1996) and Oh and Wasserman (1999). There studied joint power and rate control under Bit-Error Rate (BER) and average delay constraints. Considers thme problem of globally optimizing the transmit power and rate to maximize throughput of nonreal-time users and protect the QoS (Reiniger *et al*., 1999) of real-time users.

MATERIALS AND METHODS

System model

Energy dissipation in wireless communication: A significant part of the power consumption needed for wireless communication is due to the wireless interface, the transceiver. Typically, the transceiver can be in five modes (Fig. 1) in order of increasing energy consumption these are: off, sleep, idle, receive and transmit. In transmit mode, the device is transmitting data; in receive mode, the receiver is receiving data; in idle mode, it is doing neither but the transceiver circuit is still powered and ready to receive or transmit; in sleep mode, the transceiver circuitry is powered down, although in some implementations a small amount of circuitry is still listening to incoming transmissions.

There are basically three effects that contribute to the required energy for a transition from sleep to transmission or reception:

- The required time and energy to change the operating mode from sleep to idle
- The required time and energy the interface has to be either in idle, receive and transmit mode, but is not transmitting or receiving actual data. This is the overhead required to initiate and terminate the actual transmission. This time includes the required gap (guard time), interfacing delay, preamble and the post amble
- The required time and energy to switch to the sleep mode after transmission or reception

Priority based QOS MAC protocol: Reducing waste of energy caused by overhearing, collisions, excessive overhead and idle listening is the main purpose of most MAC-layer protocols. QoS provisioning in the MAC layer deals mainly with the scheduling of packets (Zaman and Azween, 2011) on the wireless channel subject to local limitations.

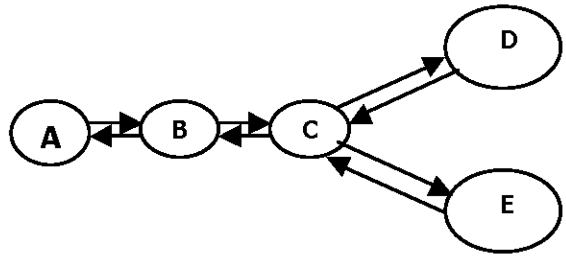

Fig. 1: Typical operating modes of a wireless modem: A: Off, B: Sleep, C: Idle, D: Receive, E: Transmit

Access to the channel that is maintained by the protocols is based on a schedule. Channel access is fixed to one sensor node at a time. Using scheduling collision of packets during accessing the channel can be avoided. However, due to dynamic nature of WSN, providing certain quality of service (QoS) guarantees in a multi-hop wireless networks, where prioritizing data packets and providing different services based on application specifics is very important. The example protocols of priority based QOS MAC protocol is namely: QMAC (QoS-aware Media Access Control), PRIMA, DB-MAC (Delay Bounded MAC), RAP, GTS (Guaranteed Time Slot).

PRIMA: PRIMA is an energy efficient and QoS aware MAC protocol that has been designed for large wireless sensor networks. PRIMA protocol is composed of two components; a clustering algorithm for providing scalability and a channel access mechanism for providing multi-hop communications. The channel access is framed of a hybrid mode of CSMA and TDMA. To communicate control messages, CSMA mode is used while data messages are assigned in TDMA slots. So, packet collisions and energy consumption can be minimized.

Algorithms:

Incremental heuristic for conflict free TDMA frame slot assigned (implemented at the sink)

Input: backbone network graph G = (V,L) M_i, $d_{i,j}$ and $P_{ix,ij}$

output: Conflict- free schematic with frame length M

for each node $_{i(i ? sink)}$ of V do

for each required slot m in Mi do

Try assigning slot s=1;

while any of the 3 interference criteria is not satisfied do

Try assigning the next slot s=s+1;

```
6:            end while
  7:              Assign slot s to required slot m of node I;
8:        end for
9:        Store the id of the last slot s assigned to
          node i, i=s;
10:   end for
  11:   Calculate the frame length M=max{, ?I ,},
     Ai, £  {2,N}
```

Notation:
TDMA-Time Division Multiple Access-> to reduce packet collision problem

- Each time slots assigned to sensor node
- Minimize the frame length (It consists of subframes) and maximize the throughput G =graph, V=edge, L=vertex, M_{i}=maximum slot, $d_{i,j}$= distance between i and j & $P_{ix,ij}$= propogation model on transmission power, time slot=s , Next time slot=s+1, Id= node parameter, frame length M=max{, ?I ,}, Ai, £ {2,N}

Algorithms (smallest period in to the shortest sub frame first scheduling algorithm):

```
Input: Packet generation periods and time slot length of L sensors
Output: Schedule for node Transmission
1: begin
2:   order the nodes in decresing priority
3:   sub frame length s=T1
4:   frame length F=TL
5:   No of sub frames m=f/s
6:   for i=1 to L
7:     allocate sensor I to the sub frame smallest  total
8:          active length
9:   repeat the time slot of sensor i every si sub
          frames
10:  end
11: end
```

Smallest period in to the shortest sub frame first scheduling algorithm(Colombo *et al*., 1999). Matrix optimization-> minimzed frame length with neural network and maximized throughput with genetic algorithm

Algorithms (Sub frame Scheduling matrix initialization):

```
1:  for u∈V do
2:    set GRAY to all member for sub frame list F_u
3:     f_uu=BLACK
4:     for v∈V do
5:        if (u,v)∈E then
6:            f_uv=WHITE
7:            for k∈V do
8:        if (k,v)∈E then
9:        f_uk=WHITE
10:             end if
11:           end for
12:         end if
13:       end for
14:         S=SU{F_u}
15:    end for
```

Sub frame scheduling matrix algorithm:

- Black node-> packet guarantee of no collision
- White node-> send a packet, may collide
- Gray node -> There is no guarantee with regard to packet collision

Algorithms (throughput maximization):

```
1:  for u∈V do
2:     for Fv∈iS do
3: If f_uv=GRAY and match(iF_u,F_V) then
4:  F_v=combine(iF_u,F_V)
5:       end if
6:     end for
7:   end for
  8:     replace all GRAY nodes in to WHITE nodes    with
Match();
```

Throughput maximization:

- Combine() and match() for reduce the frame length
- Combine() which combine sub frames but matching the suitable frames between them while matching it will be testing the data with match() function return valid, therefore white replaces with gray
- R = combine(A,B)

Mathematical notation formulae
Throughput:

$$\sigma = \sum_{j=1}^{N}\sum_{j}^{L} S^{ij} \tag{1}$$

It is the number of reserved time slots, or black slots, that are assigned to sensor node. The throughput is calculated using the equation below. The schedule matrix, S is of size |v|x|s|.|v| denotes the number of nodes ands and |s| denotes the framelength and s id the status of node in each time slot.

$$S_{ij} = \begin{Bmatrix} 1\text{ if } s_{ij} \text{ is black} \\ 0 \quad \text{otherwise} \end{Bmatrix} \tag{2}$$

Sub frame (t): This indicaite the waiting time of a sender node between to transmit. The average delay is calculated by the equation below. This metric depend upon the frame length and number of black slots per node. If any algorithm can reduce the frame length and generate the same throughput, the average delay will different.

PRIMA protocol minimizes the idle listening periods by forcing the nodes that have no data to send to go early to a sleeping state in order to save energy that is

$$\eta = \sigma / |S| x |V| \times 100 \tag{3}$$

considered as a primary source of the energy consumption in sensor networks. PRIMA protocol

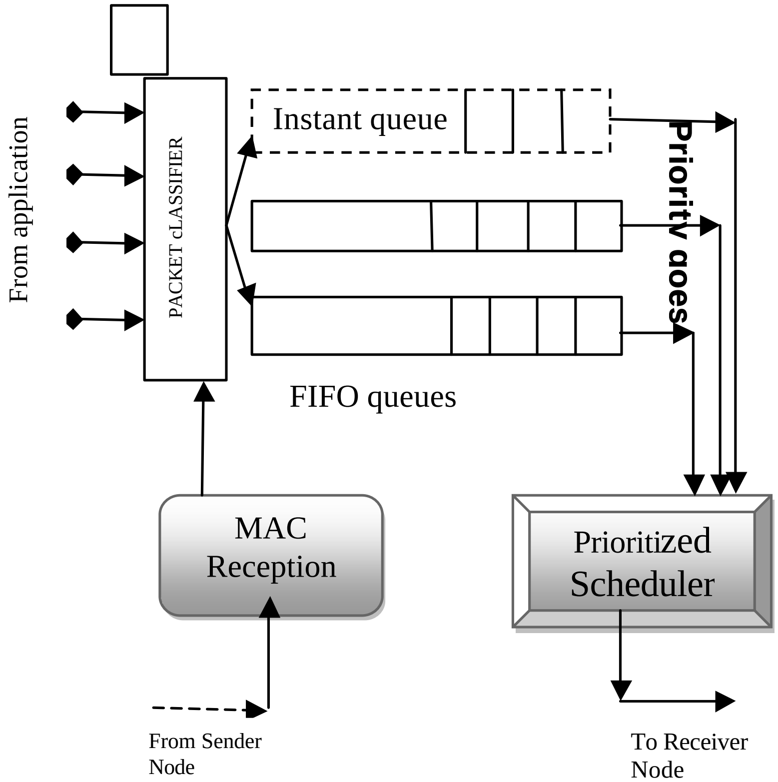

Fig. 2: Priority Scheduling in PRIMA

Table 1 :Performance comparison

Benchmark		TABU	HNN	BSC	MFA	SVC	FSM	PRIMA
20 nodes								
	S	-	-	8	8	8	8	10
	σ	20	-	20	18	18	20	26
	T	-	6.8	7	7.2	7.2	6.8	7.63
	η	-	-	17	15	15	17	17.33
40 nodes								
	S	-	-	10	9	11	10	14
	σ	37	-	35	38	37	35	53
	T	-	9.2	9.3	11	10	9.2	10.99
	η	-	-	12	11	11	12	12.62
60 nodes								
S	-	-	8	8	8	8	11	
	σ	68	-	77	71	60	64	94
	T	-	5.8	6.3	7	6.8	6	8.39
	η	-	-	24	20	19	20	21.36

provides QoS (Moorman and Lockwood, 1999) by employing a queuing model where traffics are classified depending on their importance in four different queues with different priorities such as high (instant queue), medium, normal or low. Queues with higher priority have absolute preferential action on top of low priority queues.

For doing that, PRIMA uses a sub protocol named C-MAC a modified version of Q-MAC. The source node identifies the degree of importance of each data packet that it is sending which can be converted into predefined priority levels. By appending two extra bits at the end of each data packet, the application layer sets the required priority level for each data packet. The queuing architecture of the C-MAC is shown in Fig. 2.

Simulation settings and scenarios: We compare the per-formance of PRIMA with a state-of-the-art solution SURFNet (Bacco *et al*., 2004; Chen *et al*. 1998). PRIMA and SURFNet are deployed in the wireless network whose settings are described in Table 1. The two solutions are modeled and implemented in NS-2. The media server stores 100 files and the length of each file is set to 100s. The initial target location and speed of 300 mobile nodes are randomly assigned. When the mobile nodes arrive at the assigned target location, they continue to move according to the reassigned target location and speed. We generate the information of 100 nodes (including name and introduction) and 20,200 playback logs (including played ID and time) where the information and 20,000 playback logs are used to calculate the access probabilities between nodes. 200 mobile nodes join the system following Poisson distribution and play content following generated 200 logs where the popularities of played content meet the distribution and 50 nodes play 4 files during the whole simulation time. When any node finishes the playback, it quits the system. In PRIMA, the value of threshold is set to 0.35. Before starting the simulation, the chain-based tree structure of PRIMA has been built; namely, the logical relationship between node has been defined. When the mobile nodes

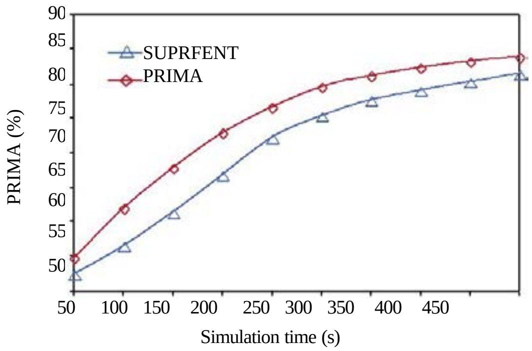

Fig. 3: ARLSR against simulation time

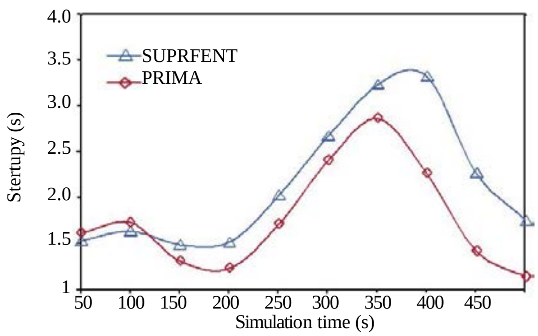

Fig. 4: ARLSR against number of nodes

join the system, they form the communities corresponding to the played node. In SURFNet, the nodes which have the long online time form AVL tree and the nodes which play the same node form a chain and attach the corresponding nodes in AVL tree.

RESULTS AND DISCUSSION

Performance evaluation: The performance of PRIMA is compared with that of SURFNet in terms of Average Resource Lookup Success Rate (ARLSR), startup delay, packet loss rate (PLR) and maintenance cost, respectively.

ARLSR: The event-request nodes send the lookup mes-sages and successfully obtain the content from the P2P network which is defined as a success lookup. The ratio between the number of successful lookups and the total number of lookups denotes the resource lookup success rate. The mean values of resource lookup success rate during a time interval of 50s and the process of node joining the system are shown in Fig. 3 and 4, respectively. As Fig. 3 shows, the two curves corresponding to the results of PRIMA and SURFNet have a fast increase trend during the whole simulation time. The increment and peak value (83.8%) of PRIMA are larger than those of SURFNet. Figure 4 also shows the increase trend of two curves with increasing number of nodes. The blue curve of SURFNet maintains a fast rise

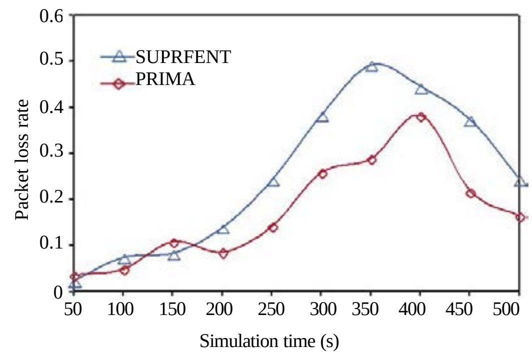

Fig. 5: Startup deley against simulation time

joining the system, but it also has an obvious fluctuation during the process of node. PRIMA curve keeps higher levels than that of SURFNet and has larger increment and peak value than those of SURFNet.

In SURFNet, the nodes with long online time are grouped into an AVL tree and the other nodes which store the same with the nodes in tree form the chain and attach the tree. In initial simulation, the nodes which have joined the system firstly form the AVL tree and obtain the resources from the media server. Therefore, the values of SURFNet ARLSR keep the low levels. The increase in the number of nodes provides the relatively enough available resources for the new system members so that the values of SURFNet ARLSR maintain fast rise. The change of user interests for the content brings the uncertainty of resource demand; namely, some nodes still do not obtain the requested resources from the P2P network and only receive the data from the server. Therefore, the ARLSR results of SURFNet keep a stable slight increment after the fast increase. PRIMA groups the nodes into a chain-based tree structure and enables the nodes to form the communities corresponding (He *et al.* (2003) to the played nodes. Moreover, the nodes prefetch the nodes of interest into local buffer and make use of prefetched resource to serve other nodes; namely, the prefetched content increases the available resources in the P2P network. Therefore, the curve corresponding to the results of PRIMA ARLSR keeps the fast rise and has higher increment than that of SURFNet.

Startup delay: The difference values between the time of sending request message and receiving first data are defined as the startup delay. The mean values of startup delay during a time interval 50 sec and the process of node joining the system are shown in Fig. 5 and 6, respectively.

As Fig. 5 shows, the two curves corresponding to PRIMA and SURFNet have two fluctuation processes during the whole simulation time. The blue curve of SURFNet experiences a slight

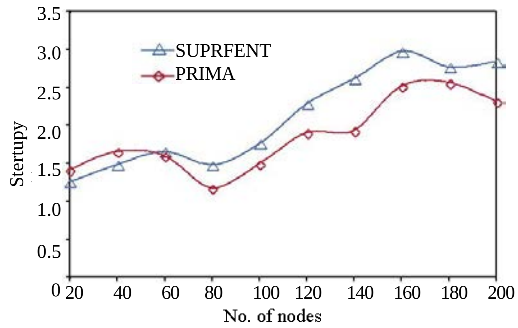

Fig. 6: Startup deley against number of nodes

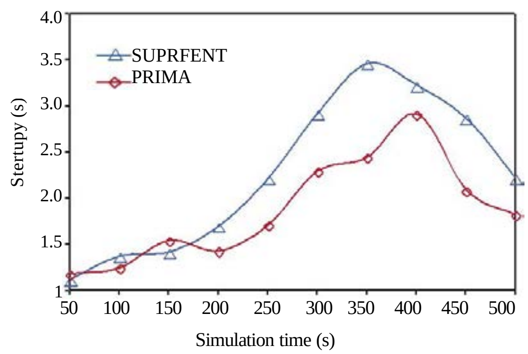

Fig. 7: PLR against simulation time

fluctuation from is equals to 50-200 sec, starts to quickly increase from equals to 200-400 sec and shows the fast fall from equals to 400-500 sec. The red curve of PRIMA has a slight increase from equals to 50-100 sec and quickly decreases from equals to 100-200 sec. The curve also keeps a fast rise trend from equals to 200-350 sec and maintains the fall from equals to 350-500 sec. The curve of PRIMA keeps lower level than that of SURFNet and has less peak value (2.87 s) than that (3.32 s) of SURFNet.

Figure 6 shows the variation process of two curves with increasing number of nodes. The curve of SURFNet has a rise trend with relatively severe f luctuation and reaches peak value (2.95 sec) when the number of nodes is 160. The curve of PRIMA also has severe fluctuation in the rise process but keeps lower level than that of SURFNet and has lower peak value (2.53 s) than that of SURFNet.In SURFNet, forwarding the request message relies on the nodes in the AVL tree; namely, the nodes in tree make use of the predefined parent-child relationship to relay the request messages. The more the number of relay nodes is, the longer the startup delay is. SURFNet can obtain low lookup delay by making use of the AVL tree structure. With the increase in the number of nodes, the amount of node streaming in network also quickly increases which leads to the network congestion. Because 50 nodes quit the system after they play 4 files, the decrease in the network congestion level enables the startup delay to quickly decrease. PRIMA analyzes the content similarity between and the playback behaviors of users to calculate the contact level between nodes. The nodes which have close contact are clustered into a chain-based tree structure. The nodes which have joined the system form the communities corresponding to the played nodes. Because the nodes in the chains have high access probabilities with each other, the request messages only experience two relay nodes, ensuring low lookup delay. Moreover, the communities may have multiple associate broker members which reduces the "distance" between the requesters and suppliers and obtains low startup delay. The request nodes in PRIMA estimate the communication quality (Lu *et al*., 2002) of transmission with the suppliers which ensures the low transmission delay. Because, the resource receivers can disconnect from current suppliers and research new suppliers when the communication quality in the transmission path decreases, the interval time relieves the congestion degree (the congestion time and level of PRIMA are lower than those of SURFNet). Therefore, the performance of startup delay of PRIMA is better than that of SURFNet.

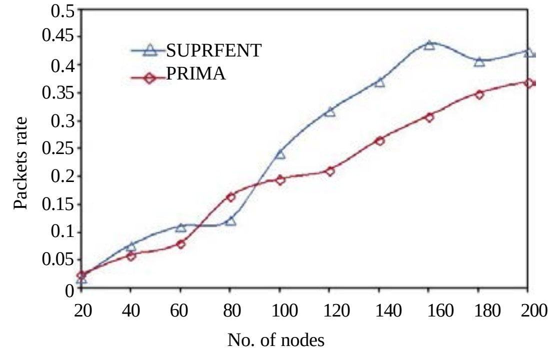

Fig. 8: PLR against number of nodes

PLR: T he ratio between the number of packets lost in the process of data transmission and the total number of packets sent denotes PLR. The mean values of PLR during a time interval 50s and the process of node joining the system are shown in Fig. 7 and 8, respectively.

As Fig. 7 shows, the blue curve of SURFNet has a fast rise from equals to 50-350 sec, keeps a decrease trend from severe fluctuation from equals to 50-400 sec, reaches the peak value (0.38) at equals to 400 sec and decreases equals to 400-500 sec. The curve of PRIMA keeps lower levels than those of SURFNet.

Figure 8 illustrates the variation of two curves corre-sponding to PRIMA and SURFNet with increasing the number of nodes. The curve of SURFNet keeps the fast trend with two fluctuations and reaches the peak value (0.43) when the num-ber of nodes is 160. Although the red curve corresponding to the PRIMA results also experiences the fluctuation, it shows a stable increase process relative to that of SURFNet and the increment and peak value (0.369) are lower than those of SURFNet.

The nodes in SURFNet do not consider the communica-tion quality in the data transmission path. The performance of data transmission easily is subjected to the severe negative influence due to the change of wireless mobile network topologies. For instance, the network congestion leads to fast increase of PLR results of SURFNet (the curve of SURFNet keeps high level from equals to 200-350 sec). The nodes in PRIMA estimate the communication quality of data trans-mission path before the construction of connection with suppliers in order to obtain the optimal performance of content delivery which ensures the low PLR. Moreover, when the resource receivers find the decrease of content delivery (if the PLR in current transmission path is larger than = 0.35), they disconnect from the suppliers and research new suppliers, which reduces the packet loss. Therefore, the PLR results of PRIMA are better than those of SURFNet.

In particular, because the network congestion may result in the large number of packet losses, the packet loss rate may have been larger than 0.35 (e.g., 0.4 or 0.5) when the receivers find the decrease of transmission performance so that the peak value (0.369) of PRIMA curve is greater than = 0.35.

Maintenance Cost: The messages used by maintaining the P2P network such as nodes joining, leaving and searching are considered control messages. The occupied bandwidth per second of control messages is defined as the maintenance cost.

Figure 9 illustrates the variation of maintenance cost results of PRIMA and SURFNet with the increase in the simulation time. The blue curve corresponding to SURFNet results keeps the fast rise with severe fluctuation from equals to 50-400 sec, reaches the peak value (4.8) at equals to 400 sec and gradually decreases from equals to 4000-500 sec. The red curve corresponding to PRIMA results has a slow increase with slight fluctuation from equals to 50-250 sec, maintains fast rise from equals to 250-400 sec and shows a decrease trend from equals to 4000-500 sec. The PRIMA curve has lower level than that of SURFNet and the peak value (4.3) of PRIMA also is less than that of SURFNet.

The maintenance cost of SURFNet mainly includes the exchange of state messages of nodes in the AVL tree, the state management of members in the chain attached to

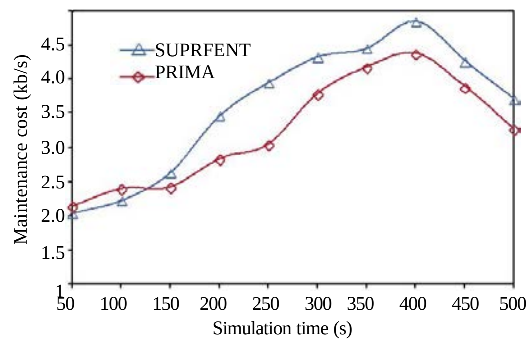

Fig. 9: Maintenance cost against simulation timev

tree, forwarding and handling the request messages of resources and the assignment of suppliers. The nodes in the tree have longer online time than those of nodes in the chain; the maintenance cost for the tree is low relative to the chain. In initial simulation, the maintenance cost of SURFNet keeps the slight increase. With the increase in the number of nodes and corresponding resource demand, the maintenance cost of SURFNet quickly increases. Because some nodes quit the system, the decrease in the number of request messages and node state lead to the fast fall of the maintenance cost of SURFNet. The dynamic change of node state is mainly the reason for the maintenance cost level of the system. The frequent change of state of nodes in the tree leads to the increase in the frequency of tree reconstruction, which results in the increase in the tree maintenance cost.The resource lookup failure indicates that the request nodes find that the resource demand cannot be met after the traversal of request messages in the whole tree, which enables the request messages to consume the large number of network bandwidth. Although PRIMA also employs the chain-based tree structure, the tree scale (height and weight of tree) keeps low level. This is because the chain includes the nodes which have close contact with the nodes in the tree. Flattening tree structure reduces the maintenance cost of tree and the negative influence caused by the state churn of nodes in tree, which also reduces the number of forwarding request messages. Some node communities have multiple broker members or associate broker members which increases the message cost of state maintenance. However, the small scale of (associate) broker members relative to the community members only results in the slight rise of maintenance cost. These (associate) broker members not only share responsi-bility for the maintenance cost of the whole P2P network and improve system scalability, but also speed up the resource lookup process and reduce the number of forwarding request messages. Moreover, sharing prefetched resources between community members promotes the resource lookup success rate, which further reduces the number of forwarding request messages. Therefore, the performance of PRIMA maintenance cost is better than that of SURFNet.

CONCLUSION

Energy-efficient packet transmission is an important aspect in wireless communication. In this study, we presented the priority based QoS aware MAC protocols have been introduced which are used in wireless networks. This proposed concept can be simulated in future. Q-MAC shows most likely the same performance of the PRIMA but in the case of packet prioritization the scheme of PRIMA is found better.

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