A Distributed Lifetime Guaranteed Mechanism in Cooperative Personal Networks

Huaizhou SHI[a], R. Venkatesha Prasad[a], Ertan Onur[a], I.G.M.M. Niemegeers[a], Ming XU[b]

[a] *Delft University of Technology (TUD, the Netherlands)*
[b] *National University of Defense Technology (NUDT, P.R.China)*

Abstract

Personal networks (PNs) have been thoroughly studied by many researchers. It is expected to play an important role in the near future along with its new form of Internet of Things (IoT). A PN is formed around a person's IoT. Most wireless devices in PNs are battery powered and need to keep track of available energy. Additionally, users always require certain lifetime guarantees for the nodes in PNs to ensure network functionalities which emphasizes more on the battery usage. The notion of cooperation brings in new methods for extending the network lifetime when it is introduced in PNs. In this paper, we propose a distributed mechanism called lifetime guaranteed mechanism (LGM) for cooperative PNs. In LGM, energy consumption budgets are dynamically set for personal devices in order to guarantee their lifetimes so as to satisfy user requirements. Furthermore, cooperative queues are proposed on both medium access control (MAC) layer and network layer to decrease packet drops and in turn congestion. We show that LGM can achieve less average end-to-end delay and lesser packet drop while network lifetime is guaranteed at the expense of lesser throughput.

Keywords: Wireless networks, personal networks, energy efficient, lifetime, ad hoc networks, cooperative networks, IEEE 802.11b, fairness, Jain's index.

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1. Introduction

While using the battery operated devices, the network lifetime is a critical aspect that decides the quality of applications. In the literature, the

Preprint submitted to International Journal of Computers & Electrical Engineering January 31, 2013

nodes are referred to as "battery-embedded", "energy-limited" or "energy-constrained" nodes [1, 2]. The problem of maximizing the lifetime is formulated by researchers as energy consumption control or "maximizing network lifetime (MNL)" problems [3, 4], which aim at reducing power consumption of nodes and thus prolonging the network lifetime. The networks which are able to solve or ease these problems are called "energy efficient", "energy aware" networks or "green radio systems" [1, 5].

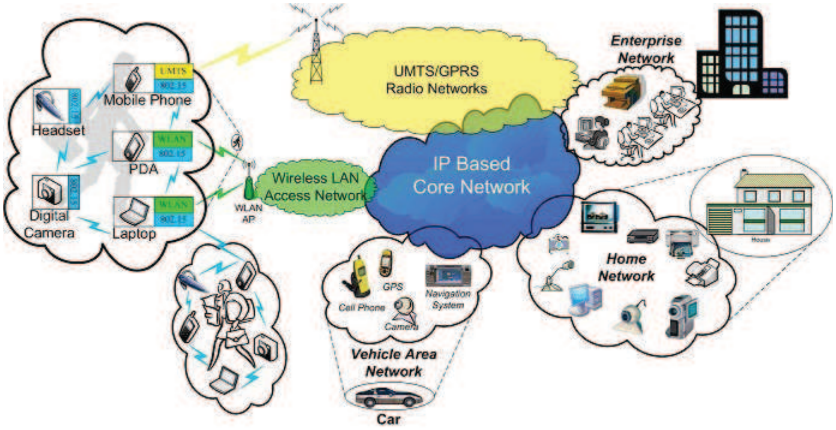


Figure 1: Personal networks.

With booming wireless technologies, from WiFi (based on IEEE 802.11) to Bluetooth, from Zigbee to MiWi ("Microchip Wireless Protocol" based on IEEE 802.15.4), more and more wireless personal devices are getting into market and are finding their places in our daily lives. Internet of Things (IoT) can bring all these devices and their offered services together along with Personal Networks (PNs). IoT [6] is a network of all devices and "things", while PNs are an overlay over IoT that interconnect all of a person's devices irrespective of their locations. For example, as shown in Fig. 1, laptops, personal digital assistants (PDAs), smart phones, printers, cameras and many other devices in houses, cars and offices are connected to each other all of which are in IoT and also in a person's PN [7, 8]. The objects that has communication capabilities are easily represented in the digital domain. However the other objects without communication capabilities are represented in the digital domain as *Virtual Objects* enabled through *helper* devices that have communication capabilities. The IoT and architecture are being investigated in the EU sponsored project iCore [6]. PNs make use of these objects and virtual objects to provide all the communication needs of a person with many of his/her devices spreading over large geographical space in a secure way [7]. Thus the PNs extend the scope of the services and connectivity in personal area networks (PANs) to a global one.

If the nodes in PNs work cooperatively to improve the services offered to a user, such PNs are cooperative PNs [7, 8]. However, many devices are battery operated and they are energy constrained devices. Ambient energy harvesting for some of these devices are being investigated for perennial operations [9], and they need to mature before being widely accepted, which is one of the goals of the GoGreen project sponsored by the Dutch government [9]. Hence, most devices still need batteries to guarantee lifetimes of the devices. For example, in Fig. 2, when multiple mobile devices share the Internet connection through a Gateway node (say, a 3G mobile) in a PN, it may be difficult to run the Gateway just on harvested energies due to heavy loads and a battery is required, however it may drain faster. Additionally, utmost only simple load balancing mechanisms are employed by wireless hubs. However, load balancing and network lifetime control are two different topics and not necessarily should go together. By balancing the load of nodes, the energy consumption of nodes may not be balanced because of different applications and power supply on devices [10]. Moreover, the low processing ability of wireless hubs significantly affects network performance. The urgency of energy consumption control in personal networks is described in [11, 12, 13]. There are some sophisticated mechanisms to prolong the network lifetime, for example in [14, 15]. However, some of the mechanisms are not suitable for cooperative PNs. Further with mechanisms based on best-effort, it may not guarantee the network lifetime. Therefore, we propose a distributed lifetime guaranteed mechanism (LGM) to ensure the network lifetime and at the same time achieve acceptable performance. We also compare the performance of IEEE 802.11b networks with and without LGM, and the simulation results show that the LGM can guarantee the user specified network lifetime with acceptable network throughput, end-to-end delay and packet drops.

The rest of this article is organized as follows. Section 2 summarizes the related work on maximizing network lifetime. In Section 3, we propose our lifetime guaranteed mechanism, and the simulation and results are described and analyzed in Section 4. Section 5 concludes the paper and discusses further work that needs to be carried out.

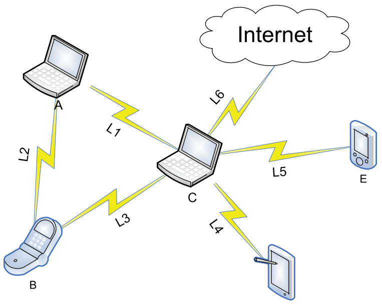
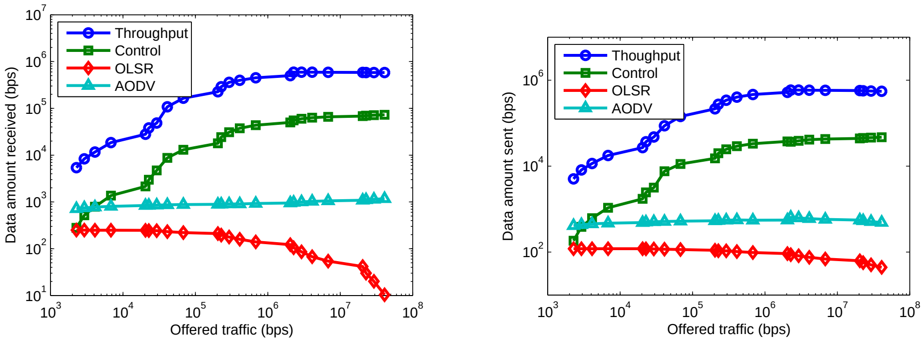


Figure 2: An example of the PNs.

2. Related Work

Power control strategies reduce transmission power of antennas to decrease energy consumption [16, 17], and because of this, lifetime can be extended [18, 19]. However, we mainly discuss the mechanisms for lifetime enhancement involving the network and MAC layers in this paper. At the network layer, balancing the load on nodes by a fair rate allocation to achieve almost similar energy consumption of nodes is one of the fundamental ideas [14, 20]. One way is to develop new energy-aware routing protocols for ad hoc networks while discovering the shortest path for packets. The other way is to select nodes in turn to work as routers to achieve fair load handling and higher lifetimes for all nodes. Both these ways try to balance the energy consumption at the nodes acting as routers [15, 21]. At the MAC layer, sleep scheduling and radio power control are the major ways to save energy [22, 23]. Sleep scheduling also prolongs lifetimes while causing least amount of degradation in throughput and delay. One simple example is that the Power Saving Mode (PSM) of IEEE 802.11a/b/g/n, in which the nodes are shut down periodically to save energy [24].

However, some shortcomings can be found when the cross-layer strategies are applied in cooperative PNs. Instead of only considering individual performances, nodes try to improve the overall network performance cooperatively. Therefore, most of the former strategies are not suitable for cooperative PNs. Furthermore, in these strategies the extension of network lifetime is based on best-effort instead of being guaranteed. Most importantly, in many energy consumption models only data packets at network layer are considered, whereas routing protocols and MAC layer management tasks generate sig-



(a) Comparison of received packets.

(b) Comparison of sent packets.

Figure 3: Data rate on Node C in the IEEE 802.11b based PN of Fig. 2, including the total data rate, the overhead generated by AODV and OLSR and MAC layer.

nificant overhead [25, 26]. An example of the extra packet transmission in a PN with five nodes (of Fig. 2) is depicted in Fig. 3. The number of control packets used in Ad hoc On-Demand Distance Vector Routing (AODV) and Optimized Link State Routing Protocol (OLSR) for different offered traffic is shown in Fig. 3. MAC layer and routing protocols generate non-negligible number of control packets, as can been seen in Fig. 3. Therefore, we try to account for these control packets too, especially in scenarios with constrained energy budgets.

Therefore, we present a distributed lifetime guaranteed mechanism (LGM) for cooperative PNs. Rate control on network layer and energy control at MAC layer guarantee the network lifetime. In LGM, all MAC layer control packets and extra routing packets are considered in the energy consumption model, which makes it more reliable. We show that network lifetime is extended significantly by LGM. Network performances, such as throughput, delay and packet drop are not too much affected by load balancing. When the traffic is heavy, the performance is even better than the standard IEEE 802.11b ad hoc networks. Fair throughput and end-to-end delay can also be found when the network is heavily loaded.

3. The Lifetime Guaranteed Mechanism (LGM)

3.1. Energy Consumption Model

We assume that the wireless nodes have four working states, which are receive, transmit, idle and pause. During receive and transmit states, wireless nodes communicate with other nodes. In the idle state nodes keep listening to the medium even though there is no communication. In the pause state, the radio is turned off but nodes may still run some applications, for example, sensing. Energy consumed in these isolated states make up the total energy consumption E_{total} (Joule) as shown in (1), where E_r, E_t, E_i and E_s (Joule) are the energy consumed in receive, transmit, idle and pause state respectively. (1) can also be written as (2), in which T_r, T_t, T_i and T_s (second) are the duration of each state, and P_r, P_t, P_i and P_s (W) are the consumed power respectively.

$$\begin{aligned} E_{total} &= E_r + E_t + E_i + E_s && (1) \\ &= T_r P_r + T_t P_t + T_i P_i + T_s P_s && (2) \end{aligned}$$

where $P_s \ll P_i < P_r < P_t$ normally [1]. There are some other energy consumption models in the literature such as [27, 28, 29, 30]. Most of them try to optimize the energy consumption at the physical layer. However, we discuss the energy consumption at the network and MAC layers. Therefore the above model, i.e., (2), is adopted in this paper.

In the literature, several different definitions of network lifetime can be found. For example, three definitions are listed in [1]:

- D1: Time till the first node dies.
- D2: Time till the failure of applications in the networks.
- D3: Time till the first partitioning of the network.

In a cooperative PN, the failure of any personal device may influence the performance of the whole network, especially when some critical applications run on them. Therefore we take the definition of D1 above in this paper as the network lifetime.

3.2. Lifetime Guaranteed Mechanism (LGM)

The goal of the network lifetime guaranteeing problem is to guarantee the network lifetime at least as long as the owners of PNs require. Since the first node failure decides the network lifetime, the best way to prolong the network lifetime is to distribute energy consumption fairly amongst nodes. This would probably make all the nodes die almost at the same time. To achieve this we try to bring in the aspect of fairness in energy consumption amongst the nodes to extend the network lifetime.

A lifetime guaranteed mechanism (LGM) is proposed to achieve user specified network lifetime through fair energy consumption amongst nodes. User specified network lifetime reflects the expectation of users or applications. It is a parameter known/set in the beginning. The main idea of LGM is that the nodes are aware of their own energy consumption and rate allocation, and then iteratively (with a time duration of T_p (second)) set energy consumption budgets. Whenever energy consumption of a node, e.g. i, exceeds its budget the pause state is triggered, in which Node i informs (via "pause" packets) its neighbors that it has already run out of its energy budget and will not receive any packets in this iteration. Once its neighbors receive this message, they build queues both at MAC and network layers to buffer the packets which are supposed to be sent to Node i cooperatively. This procedure is repeated until one of the nodes in the network dies. Fig. 4 shows one iteration of LGM.

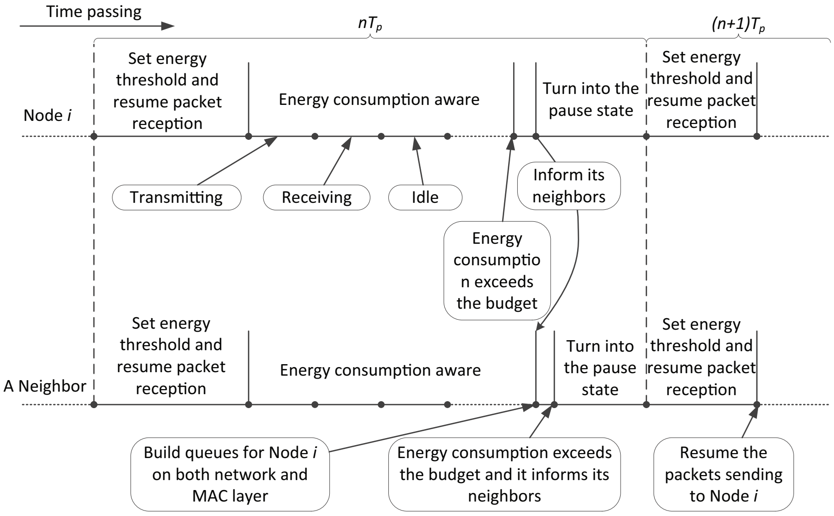


Figure 4: An example of one working iteration in LGM.

3.3. Energy Consumption Budgets

LGM tries to guarantee user required network lifetime strictly; therefore energy consumption budget in every T_p is also maintained strictly. The residual energy should be distributed in every T_p if the offered traffic is always the same. The energy budget E_{th} (Joule) in current iteration at time t (second) is shown in (3). However, in a network, the traffic is not always the same, therefore we also adopt a factor α (to induce flexibility) which can be adjusted with the fluctuations of the network traffic.

$$E_{th} = \begin{cases} (1-\alpha)\dfrac{T_p E_{re}}{L_r - t}, & t < L_r, \\ E_{re}, & t \geqslant L_r, \end{cases} \tag{3}$$

where E_{re} (Joule) is the amount of residual energy above the least possible energy for a node to function. L_r (second) is the user specified network lifetime and $\alpha \in [-1, 1]$, which offers budget flexibility in implementation. $-1 \leqslant \alpha < 0$ implies certain flexibility that the L_r may not need to be achieved exactly. On the contrary, $0 \leqslant \alpha \leqslant 1$ indicates a strict network lifetime requirement. User specified network lifetime L_r reflects the expectation of users or applications. This parameter is known in the beginning. When the network is already alive for more than L_r, then the node may use the remaining energy (E_{re}) uninterruptedly. However, if $t < L_r$, budgets for nodes are set as the predicted average consumption for each T_p.

3.4. Cooperative Queues

A "paused" node turns off its radio and stops listening and transmitting packets. To avoid packet drops in the pause state, we employ cooperative queues to buffer the packets for paused neighbors. Whenever a node receives pause information from a neighbor, it stops transmitting packets to this neighbor temporarily. All the packets which are supposed to be sent to this neighbor are buffered in cooperative queues, as shown in Fig. 5. Packets in these queues are transmitted again at the beginning of the next T_p. The cooperative queues avoid retransmissions because of paused neighbors and thus decrease the packet drops.

As we can see in Fig. 5, queues are built at the network and MAC layer separately for neighbors who are in pause state. At the network layer, the blocked packets are of three types. They are the packets generated by the node itself, the packets to be routed, which are not yet transmitted, and other packets such as broadcast packets. The packets generated by the node itself are mostly from upper layers that need to be sent to the paused neighbors, for example, the sensed data in a sensor network. If the destination of a routing packet is in paused state, then it is also added to the queue. At the

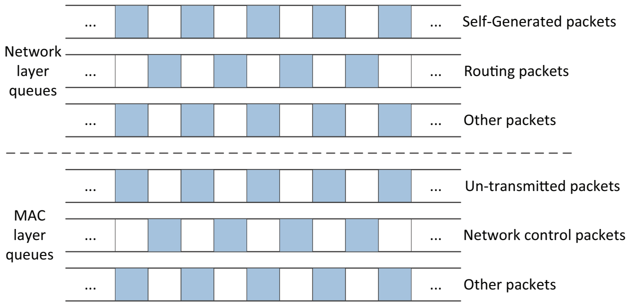


Figure 5: The cooperative queues.

beginning of the next T_p, these buffered packets on network layer are handed over to lower layers for processing.

Similar to the network layer, MAC layer has three cooperative queues too. They are queues for deferred packets, network control and management packets, and other packets such as MAC broadcast packets. The packets are deferred since the destination nodes are in pause state. Some network control and management packets on MAC layer need to be buffered to avoid the burst of control packets at the beginning of next T_p. During the next T_p these packets are transmitted first. Every node buffers packets for its neighbors to avoid dropping of the packets. Additionally, because the packets are queued by based on their type, we can easily involve a priority mechanism for packets when the network is heavily loaded. If the buffers are full, then the queues will be updated in a First-Come-First-Serve way, and the oldest packet is replaced with a new packet.

3.5. T_p

It can be easily proved that the duration of T_p does not affect the network lifetime at all when $\alpha = 0$. Although shorter T_p can lead to shorter cooperative queues, it also results in extra pause packets and switching cost. Therefore, for memory constrained or real-time personal devices, shorter T_p is a better choice, but for strict energy-constrained networks longer T_p is better.

3.6. *Performance Prediction*

For most rate limiting strategies (for example sleep scheduling), the network sacrifices the performance of nodes to achieve longer lifetime. However, as mentioned before, we adopt a pause state in LGM, which is different from

Table 1: Network performance with LGM.

Performance	Under light traffic	Under heavy traffic
Lifetime	The LGM guarantees the network lifetime.	The LGM guarantees the network lifetime.
Throughput	Almost all packets are successfully transmitted, the throughput is not affected so much.	Some packets may be dropped in the cooperative queues, which leads to decrease in throughput in heavily loaded networks.
End-to-end delay	The buffering of packets by LGM may leads to longer packet delay.	The number of packets in the network is limited by energy consumption budgets and cooperative queues. Therefore, LGM leads to less delay.
Packet drop	No extra packets are dropped due to LGM, because almost all packets are successfully transmitted.	The fact that packets are buffered in cooperative queues instead of retransmission, may lead to lower packet drop rate.
Fairness	Periodic stops may cause vacillating performance. Hence, unfairness may occur under light traffic.	Constraints on budgets induce the balance and fairer sharing of other resources.

sleep. Let us take a simple example. A sleeping sensor node stops sensing, but a paused node stops communication but still keep sensing. Therefore, the transmission of packets is stopped to guarantee the network lifetime. However, the application is still running. Hence, LGM fits well in a network where some amount of end-to-end delay is tolerable but with strict lifetime requirement. The network lifetime is guaranteed by the energy consumption budgets in LGM, which affects other performance aspects too. The influence of LGM to Network throughput, end-to-end delay, packet drop rate and the fairness under light and heavy traffic are analyzed in Table 1. We can find that LGM leads to better performance in heavily loaded networks.

3.7. The Algorithm

Details of the LGM are in Algorithm 1. The user specified network lifetime L_r is set at the beginning. Then in every iteration T_p, the energy consumption budget E_{th} is set for a node according to (3) firstly. If a node has been in pause state in the previous iteration, it starts communicating again. The node is aware of its total energy consumption. While the energy consumption does not exceed the energy budget, the node is in one of transmit, receive or idle states. Otherwise the node dies if the residual energy E_{re} falls below a certain value. Without loss of generality, we assumed that the node dies when $E_{re} = 0$. Otherwise, if the energy consumption in this iteration E_{total} reaches the energy budget of this iteration E_{th}, then the node goes into the pause state and informs its neighbors.

Algorithm 1 Lifetime guaranteed mechanism (LGM).

```
Set $L_r$;
while all nodes are alive do
  for every $T_p$ do
    Set energy consumption budget $E_{th}$ in this $T_p$ by (3);
    if this node is in pause state, then
      Resume communication;
    end if
    while the residual energy $E_{re} \neq 0 (Joule)$ and $E_{th} \geqslant E_{total}$, do
      Be aware the energy consumption $E_{total}$ in this iteration;
      The node runs in transmit, receive or idle state;
    end while
    if the residual energy $E_{re} == 0$ then
      The node dies and the network dies too;
    else if $E_{th} \leqslant E_{total}$, then
      The node switches to pause state;
      Inform its neighbors that it is paused.
    end if
  end for
end while
```

4. Simulation, Results and Discussions

We consider a PN with five nodes as in Fig. 2. In this scenario, personal devices are connected in an ad hoc fashion, and Node C acts as the gateway for Internet service. We used five identical wireless devices with unlimited buffer size in our simulation for the sake of simplicity to highlight the influence of LGM on performance. We used OLSR in our simulation because the devices are relatively static in our scenario in which AODV is not necessary. Another reason is that OLSR is a proactive routing protocol which has lesser influence to the network load than AODV. The network with standard IEEE 802.11b and LGM are examined separately. We consider IEEE 802.11b because it is one of the most widely used wireless protocols. Besides, the main purpose here is to check the energy consumption behaviour of the network, which is almost the same in the IEEE 802.11 family. We vary the offered traffic of devices from low to high to examine the performance of LGM. We assume that the network lifetime is the time duration from the start of the network until a node dies, because in a PN any failure of devices may influence the functionality of the network offering services to a user significantly. Our energy consumption model considers all packets generated by network layer and MAC layer, which makes the simulation results more reliable. Simulations were carried out on OPNET v16.0 platform, and the network topology is as shown in Fig. 2. Further, in Table 2, the parameters and their corresponding values are listed. Every node generates packets with random destinations according to the packet interval time. We have examined both the network and node performance under every packet interval time to give an overview of the performance of LGM. We run the simulation fifty times, and the average data are plotted.

4.1. Network Performance

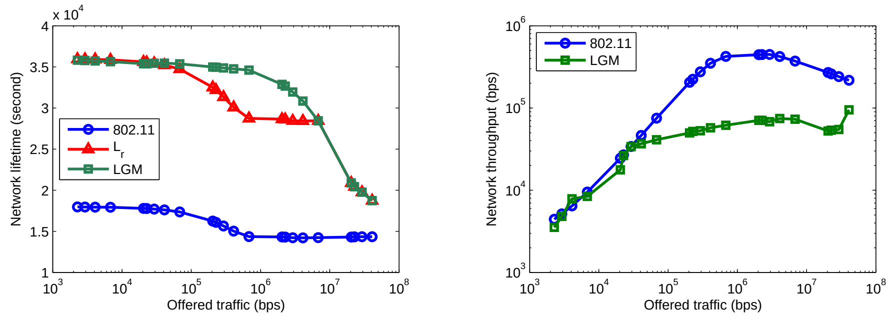
Network lifetime, throughput, end-to-end delay and packet drop under different traffic loads are examined, both with and without LGM. The fairness in terms of node throughput and end-to-end delay are plotted in Fig. 6.

4.1.1. Network Lifetime

We set the user specified network lifetime L_r as twice as that of lifetime of 802.11b networks under low offered traffic. However in order to avoid significant drop of other performance metric, we reduce L_r in cases with heavy loads as shown in Fig. 6(a) . The network lifetime of LGM can always

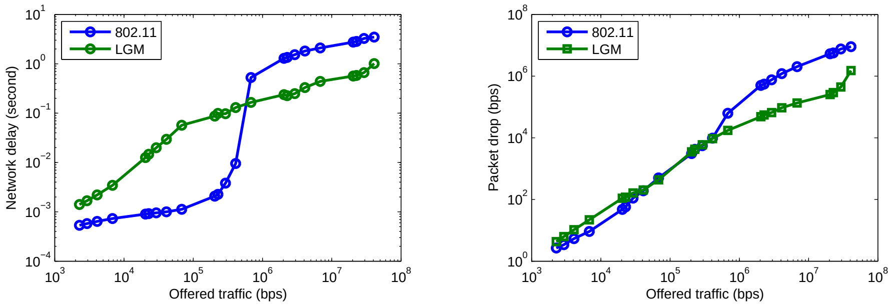
Table 2: Some variables in the simulations.

Variables	Values	
MAC layer	IEEE 802.11b	
Network layer	OLSR	
Packet interval time	0.0005 to 9 (second)	
Energy consumption	pause	0.0047 W
	Receive packets	0.9 W
	Transmit packets	1.3 W
	Idle	0.74 W
T_p	60 seconds	
α	5%	



(a) Network lifetime.

(b) Network throughput.



(c) Network delay.

(d) Packet drop.

Figure 6: Network performance under various offered traffic.

be guaranteed around L_r as shown in Fig. 6(a). In standard IEEE 802.11b network lifetime drops when the traffic grows, but when the traffic is high enough the lifetime reaches its limit and stays the same as in Fig. 6(a). This lifetime limit is reached when every node tries to transmit data all the time in standard IEEE 802.11 networks. Therefore, even though with higher offered traffic, the network lifetime stays the same.

4.1.2. Network Throughput

Fig. 6(b) reveals that, in the beginning without LGM, network throughput rises quickly as the traffic increases; however, it drops slightly when the offered traffic becomes heavy, since the capacity of the network is limited and more resources are required in the network management with the growing offered traffic. Compared to the case of without LGM, network throughput is steady with traffic growth due to the lifetime and cooperative rate control when LGM is used. LGM achieves almost the same network throughput when the traffic is sparse (less than 30kbps in Fig. 6(b)) with standard IEEE 802.11b. The network throughput is constrained since packets are buffered because of the energy budget in LGM when traffic is high. Therefore, in the heavy traffic scenarios, IEEE 802.11b can achieve higher throughput than LGM.

4.1.3. Network Delay

The trend of the average end-to-end delay is shown in Fig. 6(c) with increase in traffic. As we can find, when offered load is low, the end-to-end delay is longer with LGM than without. The pause state, which detains some packet transmission, is one of the reasons. In contrast, LGM results in less delay with dense data exchange situation (higher than 600kbps in Fig. 6(c)). This is caused by the reduction of network throughput as shown in Fig. 6(b).

4.1.4. Packet Drop Rate

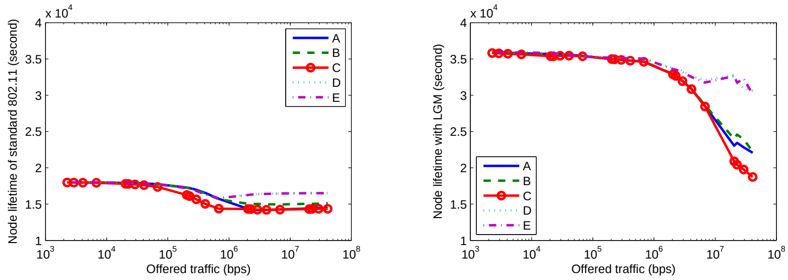
Packets are dropped when either the buffers are full or the retransmission time exceeds the maximum retries (seven times in our simulations) at the MAC layer. The packet drops in both with and without LGM cases are shown in Fig. 6(d). Despite strict limitations on lifetime, when the traffic is less than 500kbps the data dropped in LGM case is almost the same as that of the case where LGM is not used. LGM discards lesser number of packets than standard IEEE 802.11b in an heavily loaded ad hoc network. This is the consequence of throughput decrease as shown in Fig. 6(b).

4.2. Node Performance

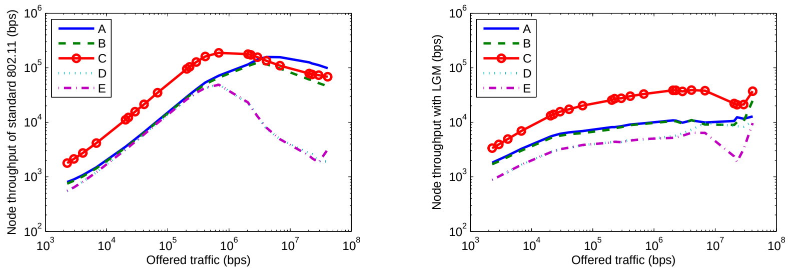
Here, we also record the performance of nodes with and without LGM with respect to the lifetime, throughput, end-to-end delay and power consumption, which are shown in Fig. 7. By comparing Fig. 7(a) and Fig. 7(b), we can see that LGM increases the network lifetime significantly. In both, with and without LGM cases the lifetime of Node C is the shortest amongst nodes, since C routes most of the packets for others. The throughput of nodes are shown in Fig. 7(c) and Fig. 7(d). When the traffic is light, the throughput of nodes is similar in both the cases. However, when the traffic grows, in the case of standard IEEE 802.11b the throughput reaches a peak at first, and then starts to drop dramatically because the network is over loaded. With the growing traffic, LGM leads to a steady and predictable performance at all nodes. Fig. 7(e) and Fig. 7(f) demonstrate the end-to-end delay on different nodes with standard IEEE 802.11b and with LGM. As we can see, Node C has the longest delay amongst all nodes, because it has much more packets to process in both the cases. In the case with standard IEEE 802.11b (Fig. 7(e)), when the traffic is heavy, end-to-end delay at all nodes rises significantly and much higher than with LGM (Fig. 7(f)). The average power consumption of nodes in their whole lifetimes are plotted in Fig. 7(g) and 7(h). The node power consumption increases with the growing of traffic when standard IEEE 802.11b is adopted, and Node C consumes much more energy than other nodes. However, when LGM is adopted, less energy consumption can be seen compared to standard IEEE 802.11b, and every node consumes almost the same amount energy. By means of balancing the energy consumption amongst nodes, the network lifetime is prolonged.

4.3. Fairness

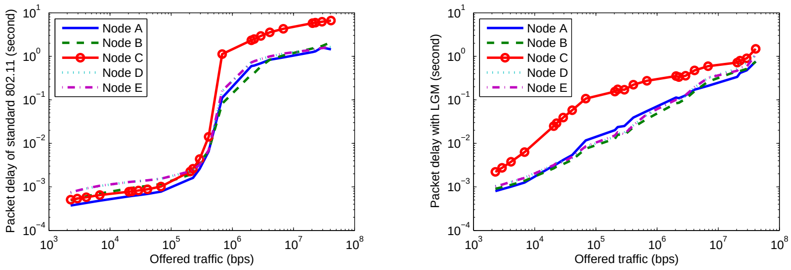
Jain's index is employed to measure the fairness level of the throughput and end-to-end delay, which is for fair resource allocation [31]. However, it can be applied as a general measure of fairness. We assume that there is a single resource and there are n individuals in the ad hoc network. $\mathbf{x} = (x_1, x_2, \ldots, x_n)$ implies the performance values, where x_i is the achievement



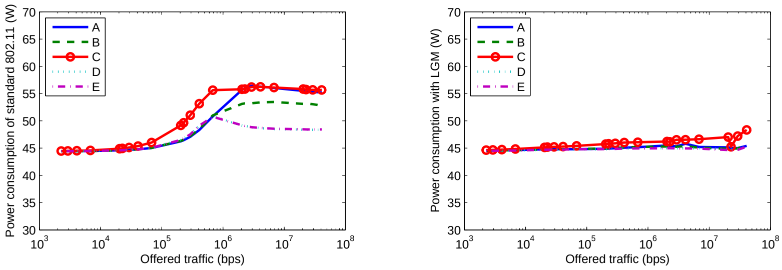
(a) Node lifetime (IEEE 802.11b). (b) Node lifetime (LGM).



(c) Node throughput (IEEE 802.11b). (d) Node throughput (LGM).



(e) Delay (IEEE 802.11b). (f) Delay (LGM).



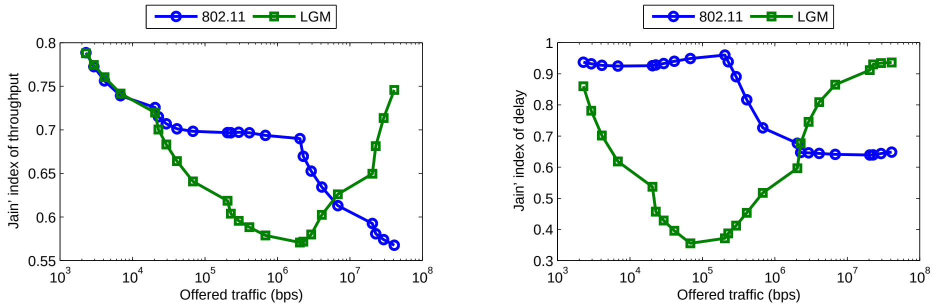
(g) Average power consumption (IEEE 802.11b). (h) Average power consumption (LGM).

Figure 7: Node performance under various offered traffic.

of the i^{th} individual. Subsequently, Jain's index is,

$$f(\mathbf{x}) = \frac{\left[\sum_{i=1}^{n} x_i\right]^2}{n \sum_{i=1}^{n} x_i^2}, \tag{4}$$

where $0 \leq f(\mathbf{x}) \leq 1$.



(a) Jain's index of node throughput.

(b) Jain's index of end-to-end delay.

Figure 8: Fairness under various offered traffic.

We measured the fairness of node throughput and end-to-end delay with and without LGM as shown in Fig. 8. Throughput fairness is given in Fig. 8(a). For standard IEEE 802.11b networks, the fairness of both throughput and delay has the same trends. For lighter traffic, IEEE 802.11b provides fairness to nodes because almost every node can be satisfied. However when the traffic grows rapidly, the throughput fairness of IEEE 802.11b drops due to its best-effort nature. LGM causes more unfairness with moderate traffic. However, throughput fairness rises dramatically with the increase in traffic in case of LGM. This is due to the balancing of throughput by energy budget. Similar tendency can be seen in Fig. 8(b). Despite unfairness in sparse traffic cases, LGM equalizes end-to-end delay on different nodes by balancing the throughput in cases with heavy loads.

The above figures confirms the results we predicted in Table 1. The influence of LGM to throughput, end-to-end delay, packet drop rate and fairness are mainly due to the constrained network lifetime. The energy consumption budgets in LGM affect node traffic, which lead to balanced load amongst nodes. With sparse traffic, the effect of load balancing is not significant because most of the energy is spent on idle. While using LGM, and if the traffic is higher, we observe lesser end-to-end delay, lesser packet drop rate, and fairer throughput because of the constraints on the traffic admitted by the gateway node (Node C) or the nodes themselves.

5. Conclusions and Further Work

Based on the study and the results, we note that LGM ensures the network lifetime by a distributed method in cooperative PNs. Cooperative queues are introduced in LGM, which decrease the packet drops significantly. Better performance can be achieved when network is heavily loaded. Even though LGM may cause some unfairness in lighter traffic case, fairness can also be improved by LGM under heavy traffic. The involvement of cooperative queues requires more buffers and memory, while we can control the queue size by setting short T_p value. Decrease in throughput by LGM may be kept to a minimum with relaxed lifetime constraint α. Lifetime and energy control in cooperative PNs considering complex scenarios needs to be still studied. Further, we want to bring in the notion of importance/priority of services and study the cases where heterogeneous connectivity is involved with different network structure and routing protocols, as well as mobility.

6. Acknowledgments

We thank the iCore project. This article describes work partially undertaken in the context of the iCore project, 'Internet Connected Objects for Reconfigurable Ecosystems' (http://www.iot-icore.eu/). iCore is an EU Integrated Project funded within the European 7th Framework Programme, contract number: 287708. The contents of this publication are the sole responsibility of iCore project and can in no way be taken to reflect the views of the European Union.

We also thank Go-Green project. This article describes work partially undertaken in the context of the Go-Green project (http://gogreen-project.nl/). Go-Green is sponsored by the Dutch Ministry of Economic Affairs, Agriculture and Innovation.

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Huaizhou SHI received his Bachelor's Degree in 2006 and Master's Degree in 2008 from National University of Defence Technology, P.R. China. He is currently pursuing Ph.D. at Delft University of Technology, the Netherlands. His research interests are fairness issues and resource allocation in wireless networks, Cognitive Radio Networks, peer to peer IEEE 802.22 networks(P2PWRAN), and Zigbee networks.

R. Venkatesha Prasad received a Ph.D. degree in 2003 from Indian Institute of Science, Bangalore India. Currently, he is an Assistant Professor at Embedded Software Group, Delft University of Technology, working on the EU funded projects iCore, GoGreen and SOWICI and guiding graduate students. He is the secretary of IEEE ComSoc Standards development board, and associate editor of Transactions on Emerging Telecommunications Technologies.

Ertan Onur received the Master's and Ph.D. degrees in computer engineering from Bogazici University, Istanbul, Turkey in 2001 and 2007, respectively. Presently, he is an Assistant Professor at Embedded Software Group, Delft University of Technology. His research interests are the collective adaptive systems and ad hoc networks. He developed and managed many commercial telecommunications applications, and has a patent.

I.G.M.M. Niemegeers received a Ph.D. degree in 1978 from Purdue University in West Lafayette, Indiana, USA. Since May 2002 he holds the chair of Wireless and Mobile Communications at Delft University of Technology, where he is heading the Telecommunications Department. His present research interests are 4/5G wireless infrastructures, future home networks, ad hoc networks, personal networks and cognitive networks.

Ming XU is a Professor and the head of Network Engineering Dept., National University of Defense Technology (NUDT), China. He got his Bachelor's and Master's degree from Wuhan University in 1984, 1987, and Ph.D. from NUDT in 1995, respectively. He is a senior member of CCF and IEEE. His recent research interests include wireless networks and mobile data security.