BQPS: A Broadcast Mechanism for Asynchronous Quorum-based Power Saving Protocols in Ad-Hoc Networks

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Received 9 February 2009; revised 3 October 2009; 16 October 2009

Abstract

Quorum-based power saving (QPS) protocols allow “asynchronous” wireless hosts, operating in a multi-hop ad-hoc network, to tune to the low power mode conceived in IEEE 802.11 MAC standard. QPS schemes guarantee that the wake-up schedule for every two neighboring hosts would ultimately overlap within a bounded latency so as to be able to accomplish their reciprocal “unicast” communications. A major drawback in quorum-based rendezvous schemes, however, lies in the absence of an efficient mechanism for enabling the simultaneous re-activation of all PS neighbors to receive “broadcast” messages. In this paper, a novel asynchronous wake-up scheduling mechanism is proposed, which specifically tackles the broadcast transmission problem in QPS systems. We introduce a special control packet at the MAC layer through which a sending host notifies its neighbors of forthcoming broadcast traffic, allowing the receivers to estimate the approximate re-activation time for ensuring the successful delivery of the messages. We will investigate, analytically, the optimum frequency with which to emit notifications so that the energy overhead induced is minimized in both single-hop broadcasting as well as network-wide flooding scenarios. Evaluation results derived from our simulation experiments reveal that the proposed mechanism can effectively improve the performance of an asynchronous QPS system in terms of both throughput as well as energy saving ratio; for instance, when operating with a wake-up ratio of 16%, network throughput will be enhanced by at least 60% in comparison with the existing schemes.

Keywords: Power saving protocol, Quorum system, Multihop ad-hoc network, Broadcast protocol.

1. Introduction

A mobile ad-hoc network (MANET) is typically formed opportunistically from a more or less coincidental set of communicating devices, none of which have the capability to provide infrastructural service. The participating nodes have to undertake routing tasks in addition to hosting application-level entities. Popular operating scenarios for MANETs include communications in battlefields, disaster rescue operations, as well as on-the-fly deployment in special events such as conferences. The absence of a plug-in power together with the limited battery capacity of portable devices makes energy conservation an indispensable part of every successful MANET-driven implementation.

Conventionally, IEEE 802.11-based low power mode management [1], which is founded on the notion of periodic wake-up scheduling, has been at the center of a substantial stream of the research efforts in devising energy saving protocols to extend the lifetime of wireless hosts. Given that communication tasks consume a considerable portion of the wireless nodes’ limited power resources, wake-up based power management schemes intend to save energy by having the wireless interface card switch to sleep mode when it is not required to be active.

The power-saving mode in IEEE 802.11, however, has originally been conceived to operate correctly only in single-hop (i.e. fully-connected) ad-hoc networks wherein the participating hosts are supposed to be clock-synchronized through the periodic transmission of beacons. If this protocol is to be applied in a multi-hop ad-hoc setting, several problems may be encountered, including costly clock synchronization and even incorrect network partitioning [2, 3]. The MANET’s dynamic topology together with the unpredictability of the variations in connectivity patterns renders global synchronization too costly and almost infeasible, which is why researchers within the community have attempted to devise PS protocols for specific use in the context of “asynchronous” ad-hoc networks [3, 4].

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One significant line of research in this area has been associated with the translation of classical quorum systems to an asynchronous power saving scheme for MANETs [5]. In [3], it is shown that any quorum system satisfying the *rotation closure property* can be deemed as one such potential solution. In QPS, the arrangement of hosts' wake-up intervals is performed in a manner so as to guarantee that two arbitrarily time-asynchronous hosts can hear each other at least once within a bounded latency.

In this paper, we investigate the applicability of QPS protocols in the "broadcasting" domain. Broadcasting is a major communication primitive as well as a fundamental building block required by many applications and protocols in MANETs. It is frequently deployed as an underlying service to provision for synchronization as well as for communicating control data [6, 7, 8]. In effect, the correct operation of many protocols in ad-hoc networks such as routing relies on the efficient transmission of broadcast packets. However, the quorum-based asynchronous PS protocols can only ensure the "pair-wise" rendezvous of the PS hosts; in other terms, when it comes to sending broadcast traffic, the QPS system does not guarantee the simultaneous reactivation of all neighboring nodes.

A naive approach would be to have the sending host repeatedly transmit the broadcast packet [3, 4, 9, 10] so that each neighboring host ultimately receives the message in its corresponding active period. Obviously, such a basic re-transmission approach would increase both the one-hop delivery latency of the broadcast packets as well as the energy consumption of the sending host. An alternate approach would be to draw on a simple "busy waiting" technique [11], requiring that each neighboring host, once delivered a broadcast notification, remain active till all intended receivers are informed of the forthcoming traffic. As opposed to the repeated transmission mechanism, the relatively efficient behavior at the sender's side in this approach comes at the expense of increased energy consumption at the receivers' side; i.e. the sooner a neighboring host enters the busy-waiting loop, the more time it has to spend in idle monitoring.

In this article, we propose a novel PS broadcast mechanism for asynchronous ad-hoc networks, henceforth referred to as BQPS (i.e., Broadcasting in Quorum-based PS) which can be easily incorporated into existing QPS protocols. Unlike the above-mentioned basic mechanisms, BQPS would require the transmitter to send the broadcast packet only once, while also having the receivers wake up simultaneously at the time of the transmission. As it will be demonstrated through simulation experiments, our approach promises a significant reduction in the one-hop delivery latency of the broadcast traffic and will also achieve higher throughput in comparison with the naive "re-transmission"-based techniques or with those relying on a simple "busy-waiting" polling strategy. The superiority of the performance of our approach becomes even more noticeable in cases where the wake-up ratio is very low (e.g., 16%) or when the network is densely populated.

The rest of the paper is organized as follows: In section 2, we discuss the background research as well as the related work in the area of power-saving protocols for ad-hoc networks. The details underlying our BQPS mechanism will be presented in section 3. In section 4, we report on the simulation experiments conducted and will also discuss the outcome of several performance comparison results. The paper ends with conclusions.

2. Background and Related Works

2.1. IEEE 802.11 PS mode

The IEEE 802.11 standard [1] makes provisions for managing two different power modes at the MAC layer: *active* mode (AM) and *power-saving* mode (PS). In the AM mode, the radio interface of the wireless hosts will always be kept in the monitoring state, readily available for receiving or transmitting the messages; therefore, nodes would be able to immediately interact with their communication partners. However, given that the energy consumed by the wireless hosts in the monitoring state is almost the same as that in the receiving state, the PS mode is accordingly conceived so as to reduce the time spent in idle monitoring. Figure 1 illustrates the basic mechanism underlying the IEEE 802.11 PS mode. The time axis will be divided into equal-length *beacon intervals,* with a small window at the beginnings during which wireless hosts are expected to be active. These short periods are referred to as the ATIM (Announcement Traffic Indication Map) windows. During the ATIM windows, all wireless hosts in PS mode will wake up simultaneously and handle the transmission or the receipt of the control messages. During the rest of the beacon interval, hosts will remain active or else enter the doze state depending on whether or not they have received an ATIM notification.

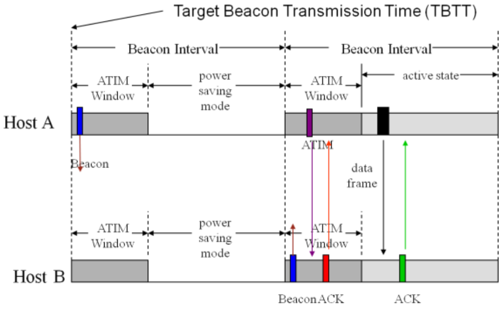

Fig.1. IEEE 802.11 PS mode.

It is expected that all radio interfaces in PS mode will wake up simultaneously in their associated ATIM windows since hosts are assumed to utilize TSF (Time Synchronization Function) in order to synchronize their duty cycles. However, it is not a trivial task to achieve global synchronization in multi-hop ad-hoc scenarios featuring longer communications delay and more frequent network partitioning. In these scenarios, providing for synchronized communication becomes even more costly or virtually infeasible as the network scales up [4]. Hence, in the general sense, we have to deal with the fact that nodes may be asynchronous in their ATIM windows and thus have to communicate in the presence of clock skew.

2.2. Quorum-based Power Saving Protocols (QPS)

Quorum-based power saving has established a significant line of research in designing protocols intended to prolong network longevity in "asynchronous" ad-hoc scenarios [2, 3, 4, 9, 10]. In QPS, the concept of a *quorum system* is utilized to guarantee rendezvous between any two arbitrarily time-asynchronous PS hosts within bounded time intervals.

The QPS problem is formally defined as follows [3]: A universal set $U = \{0, 1, \ldots, n-1\}$ $(n \geq 2)$, is given, representing *n* consecutive beacon intervals. The goal is to determine under U a quorum system Q, which is a collection of pair-wise non-disjoint subsets of U, each called a *quorum*, such that every mobile host is free to pick any quorum $G \in Q$ to represent all its active intervals. The quorum system Q has to guarantee that for any two arbitrarily time-asynchronous hosts A and B, host A's beacon windows are fully covered by host B's active durations at least once in every n consecutive beacon intervals, and vice versa. In [3], the notion of *rotation closure property* has been defined for a quorum system, arguing that only the systems satisfying this property are apt for arranging rendezvous between the asynchronous hosts' wake-up schedule.

A QPS system typically considers two types of beacon intervals [3]: quorum intervals and non-quorum intervals. As depicted in Figure 2, the quorum interval is a period of full activity; it starts with two specific windows, a beacon window (BW) followed by an MTIM window, and also requires that the host remain active (in monitor mode) for the rest of the beacon interval. A station may broadcast a beacon frame only in its BW. On the other hand, each non-quorum interval begins with an MTIM window, and allows for a PS host to save on energy by entering the doze state for the rest of the interval.

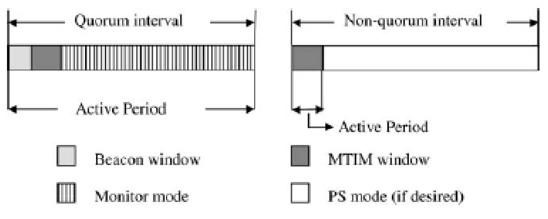

Fig.2. The structure of quorum and non-quorum intervals [3].

Much in the same way as in IEEE 802.11, a host with buffered packets may compete to send notifications to intended PS receivers, and accomplish the necessary handshaking within the MTIM window.

2.3. Broadcasting and QPS

Power saving based on the notion of period wake-up scheduling may adversely affect communicating broadcast packets in a multi-hop ad-hoc scenario. While unicast transmissions warrant confirmation from the intended receiver, broadcast messaging is by default carried out without feedback; hence, it might frequently be the case that neighboring nodes, operating in PS mode, simply miss broadcast messages which happen to arrive in their sleep period. Consequently, providing for the low power mode in the broadcasting domain, calls for specific considerations to ensure the delivery of the messages. The QPS systems discussed in [3, 4, 9, 10], require that a broadcast message (e.g., an AODV *route_request*) be sent multiple times in case that the sending host realize some of its neighbors are operating in the PS mode. The re-transmission-based mechanism is dependent on exact a priori knowledge of the neighboring hosts' wake-up schedule to ensure the delivery of the broadcast packets. Additionally, the energy overhead at the transmitter's side would become more significant as the number of nodes in the vicinity or the quorum system size grows. Such repeated transmissions also affect the one-hop latency incurred by a broadcast packet, resulting in lower efficiency in terms of network throughput.

The busy waiting approach [9], on the other hand, works by notifying the receivers, one after the other, to maintain their monitoring state till the actual broadcast message is transmitted. Obviously, the sooner a receiver gets informed of the broadcast traffic, the more time it has to spend in busy-waiting loop, resulting in its higher susceptibility to energy depletion. In the worst case, all but one of the neighboring hosts might have entered the busy-waiting state, while the transmitter is still waiting for the last host to wake up for receiving the forthcoming broadcast message. Similar to the re-transmission-based technique, the delay incurred by broadcast messages would be aggravated with the increasing number of nodes or as the quorum system grows in scale.

3. BQPS

3.1. Main Protocol Operation

In our proposed quorum-based broadcasting mechanism, we also envisage two types of beacon intervals. As shown in Figure 3, *quorum intervals* start with a beacon window and the host is supposed to maintain its monitoring state during the rest of the interval. *Non-quorum intervals*, on the other hand, start with a special BTIM (Broadcast Traffic Indication Message) window and let the host go to sleep in case it is not to be concerned in any send or receive operation.

As illustrated in Figure 3, the structure of a non-quorum beacon interval in our approach differs from that in the original QPS [3]. Throughout the BTIM window, at the beginning of the interval, the host is supposed to be awake and keep listening to the medium so as to be able to receive special BTIM packets (if any). Also, the ATIM-ACK handshake mechanism would not be utilized here. A BTIM packet is a control packet in MAC layer which mainly consists of the source address, destination address (MAC-Broadcast) and a BTIM number.

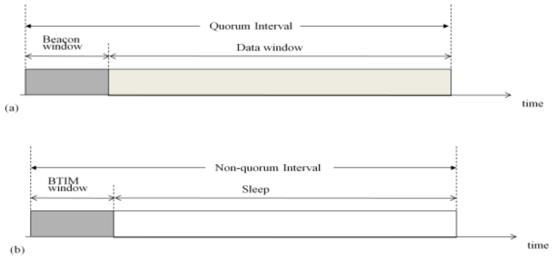

Fig. 3. Beacon interval structure for quorum and non-quorum intervals.

In BQPS, the transmitter notifies all its neighbors of the forthcoming broadcast traffic by sending in advance a total of n BTIM packets for the duration of one full beacon interval. The time between every two BTIM transmissions (t) is defined as follows:

$$t = BTIM\ Window\ Size - txtime(BTIM) \qquad (1)$$

and

$$n = \left\lfloor \frac{Beacon\ Interval\ Size}{BTIM\ Window\ Size - txtime(pkt)} \right\rfloor + 1 \qquad (2)$$

Theorem 1: In case no collision occurs, the BTIM notification mechanism will guarantee that each neighboring host receives at least one BTIM packet within its active period.

Proof: We prove by contradiction; Let A and B be two asynchronous PS hosts in a MANET. Host A, with broadcast traffic to send, emits n BTIM packets starting at t_0 and re-transmitting every t seconds. The time it takes to send all BTIM notifications will be calculated as follows:

$$T = n \times t \geq Beacon\ Interval\ Size \qquad (3)$$

Suppose that B is a neighboring host which has missed all BTIM packets; there are two possibilities: (1) B has been in the sleep mode for a period of T seconds; obviously, this case contradicts with the beacon interval structure in BQPS which requires that a node stay awake at least as long as the length of a BTIM window. (2) Two consecutive BTIM packets have been emitted with more than t second lag in between, a case which is simply presumed to never occur; hence, Theorem 1 is true.

The sending host will remain active until it finally transmits the broadcast message. A neighboring host receiving a BTIM notification will insert its associated number as well its arrival time into a specific table. For every BTIM packet received, a timer will also be associated in its corresponding table entry, namely *WaitingforBcastTimer*. The neighboring host intended to receive the broadcast message is supposed to be (or become) active when this timer expires. Knowing the BTIM number, a receiver may calculate the waiting time (W) as follows:

$$W = [n - k] \times \left(BTIM\ Window\ Size - txtime(BTIM)\right) \qquad (4)$$

This way, BQPS would have no need to alter the nodes' wake-up schedules in order to receive the broadcast packet. Also, the sending host is not required to re-transmit the message multiple times to ensure complete delivery. Figure 4 sketches the outline of the broadcast mechanism in BQPS.

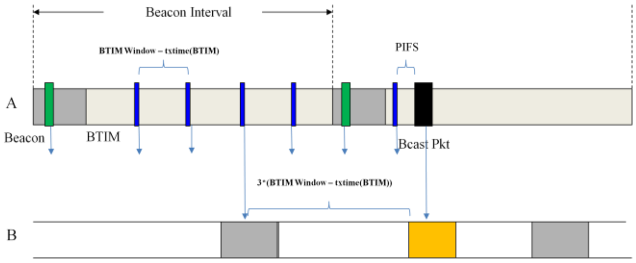

Fig. 4. Schematic of the BQPS mechanism.

In order to avoid collisions, the sending host draws on the DCF access method whenever a BTIM packet is to be emitted; the inter-frame space (IFS[*]) for BTIM notifications is set equal to DIFS. The transmitter, thus, first senses the medium to see if it is idle and then waits for the duration of a DIFS before finally sending the BTIM packet. Broadcast transmissions, however, will be handled differently; to assign the highest priority to broadcast messages in comparison with the other MAC-layer packets, the sending host, once done with all BTIM notifications, waits for the duration of a PIFS before actually transmitting the message. Moreover, to avoid concurrent BTIM transmissions from neighboring nodes, a host will have to defer its own broadcast transmission until it receives the already advertised traffic.

An important issue in QPS protocols is the periodic transmission of beacon frames as the underlying mechanism for neighbor discovery and maintenance in MANETs; hence, sending BTIM notifications should, by no means, impede the transmission of beacon frames. Accordingly, in BQPS, each time a sending host is going to emit a BTIM notification, it verifies to see if there is also a beacon frame ready to send. In case the two coincide, BTIM notifications will be piggybacked on beacon frames (see Figure 4).

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[*] The IEEE 802.11 standard defines a number of inter-frame space intervals including SIFS (Short Inter-Frame Space), PIFS (Priority Inter-Frame Space), and DIFS (DCF Inter-Frame Space) to help prioritize the transmission of different types of frames; the IFS values are supposed to meet the following inequality: SIFS < PIFS < DIFS.

3.2. BTIM Window Size: An Analytical Investigation

The BTIM window size and the number of BTIM notifications sent for an intended broadcast transmission are the two determining factors in BQPS to influence the lifetime of the network. In this section, the BTIM window size will be investigated analytically so as to determine the optimum value for which the average broadcast energy consumption would be minimized. Intuitively, although a small size for the BTIM window would reduce the energy consumed in idle mode at the beginning of the non-quorum intervals, it also implies a larger number of BTIM notifications required to be sent for each broadcast message; in other words, there is a trade-off between the energy consumption in terms of the BTIM window size and the number of BTIM notifications.

Here, we will discuss how to find the best BTIM window size by estimating the BQPS-induced energy overhead in both the sending and neighboring hosts as well as the overhead imposed on the entire network in a possible MANET-wide flooding scenario.

Given that a sending host is supposed to emit n BTIM notifications prior to any broadcast transmission, the additional energy consumed in transmitter (S) would be calculated as follows:

$$S = n \times s \tag{5}$$

In the above equation, s denotes the energy consumed to send a single BTIM notification and $n = \lfloor BI/(BTIM - t) \rfloor + 1$. BI and $BTIM$ denote the length of a beacon interval and BTIM window size respectively. t is the time it takes to transmit a BTIM packet.

Obviously, the energy overhead imposed on a neighboring host from when it receives a BTIM notification until the broadcast packet actually arrives would differ depending on whether it has initially been in a quorum or a non-quorum beacon interval. A host may receive more than one BTIM notification in case it is active in its quorum interval. Supposing that the first arrived BTIM is the sender's kth notification, the neighboring host may ultimately receive a maximum of n-(k-1) BTIMs in the worst case. To estimate the average energy overhead, we will assume that the probability of receiving BTIM packets follows a uniform distribution and equals to $\frac{1}{n}$. The average energy consumed in a neighboring host which receives a BTIM in its quorum interval is, thus, calculated as follows:

$$A = r \times \sum_{k=1}^{n} \left[\frac{1}{n} \left(n - (k-1) \right) \right] \tag{6}$$

r denotes the energy required to receive a single BTIM notification.

On the other hand, in case a neighboring host receives a notification in the BTIM window of a non-quorum interval, the additional energy consumed *(B)* will be calculated as follows:

$$B = BTIM \times P_{idle} \tag{7}$$

P_{idle} is the denotes the energy consumed by a node in its idle mode.

We derive a probabilistic expression that allows us to estimate the average energy consumed in neighbors to receive a broadcast packet. A node adopting a QPS mechanism would be in a quorum interval with the probability of $1/\sqrt{Q}$ where Q is the size of the quorum system. The probability that some m out of a total of M neighboring hosts receive a BTIM notification in their quorum interval can be formulated as a binomial distribution:

$$P_m = \binom{M}{m} \left(\frac{1}{\sqrt{Q}} \right)^m \left(1 - \frac{1}{\sqrt{Q}} \right)^{M-m} \tag{8}$$

Also, as discussed in [12], assuming the uniform distribution of nodes, the probability that a sending host be adjacent to exactly M neighbors can be calculated approximately using the following formula:

$$P_M = \binom{N}{M} \left(\frac{\pi {r_0}^2}{a} \right)^M \left(1 - \frac{\pi {r_0}^2}{a} \right)^{N-M} \tag{9}$$

r_0 denotes the transmission radius of the nodes and a stands for the area of the network.

Consequently, the overall energy overhead induced by the BQPS mechanism to receive a single-hop broadcast can be estimated using the following equation:

$$R = \sum_{M=1}^{N-1} \sum_{m=0}^{M} [P_M P_m (mA + (M-m)B)] \tag{10}$$

In a MANET-wide flooding scenario, however, every node would have to re-broadcast the original message until it is received by all nodes distributed within a maximum of h hops across the network. The overall energy overhead for this scenario can be estimated as follows:

$$E_{total} = NS + E_{recv}(h) \tag{11}$$

where $h = \frac{l}{r_0}$ (l denotes the network diameter) and

$$E_{recv}(h) = \sum_{M=1}^{N-1} \sum_{m=0}^{M} P_M [P_m (mA + (M-m)B) + \\ MErecvh{-}1 \tag{12}$$

Table.1 lists the minimum values calculated for E_{total} according to equation (12) in milliseconds. Q and N represent the quorum size and the number of nodes respectively.

Table 1
Optimal BTIM window size in milliseconds.

N	Q = 10	Q = 20	Q = 40
10	4	4	3
20	5	4	4
30	5	5	5
40	6	6	6

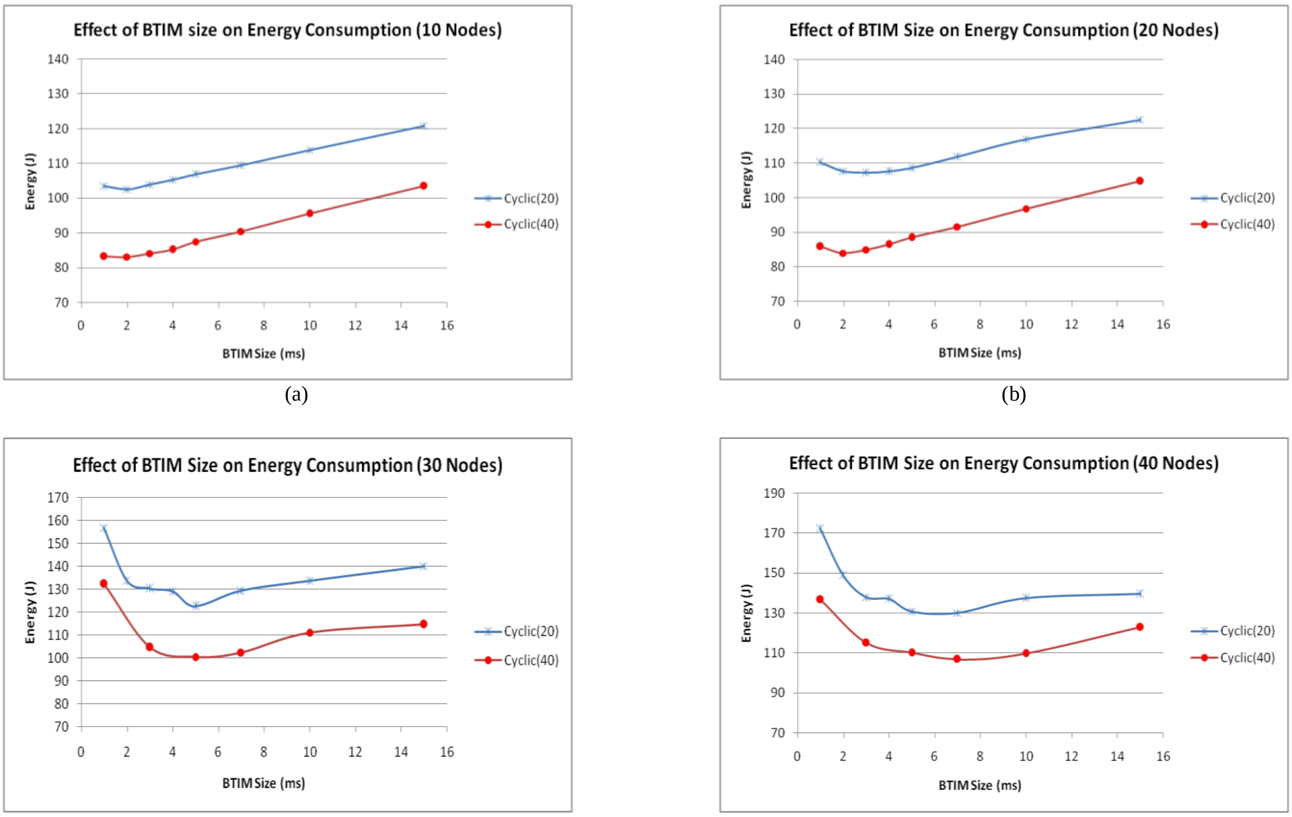
As Table 1 depicts, the average BTIM window size calculated with respect to equation (12) is 4.7 ms, which, as will be demonstrated in section 4, has also been corroborated by empirical results.

4. Performance Evaluation

We have evaluated the performance of our protocol by means of a detailed simulation study based upon NS-2, a popular open-source simulation system. We have modeled the physical and data link layers using the simulator's built-in wireless components. Specifically, we adopted an 802.11 MAC into which we integrated a custom implementation [10] of both the PSM mode as well as the beacon transmission mechanism. The quorum system implemented is cyclic [3] and we consider a reference scenario consisting of up to 40 hosts randomly distributed across a 1000m×1000m square area. We have chosen AODV as the network-layer routing protocol and the reference packet size is assumed to be 512 bytes. Transmission range of the hosts is set equal to 300 meters and their movement follows the random way-point mobility model, with the average velocity of 10m/s and a pause time of 20s. The length of the beacon interval is set to 100 ms, the signal propagation follows the two-way ground model and each node is assumed to be equipped with an omni-directional antenna. The nodes' initial energy is set to 300 Joules and the power consumed in "transmission", "receive", "listen" and "idle" modes is assumed to be 1.4, 1.0, 0.83 and 0.13 mw respectively, in compliance with measurements reported for Cabletron Roamabout network interface card in [14].

In the first set of experiments, we investigated the best BTIM window size for which energy consumption is minimized as we varied the number of nodes between 10, 20, 30 and 40, for two quorum system sizes of 20 and 40. As Figures 5 (a) and (b) illustrate, the optimum length for BTIM window would decrease in quorum systems of larger sizes; in other terms, the smaller the ratio of the wake-up intervals, the fewer the number of the received notifications, effectively making the BTIM window size the dominating factor in determining the overall energy overhead. It is also easy to note that this behavior is quite consistent with the outcome of our analysis. Moreover, a larger value for the BTIM window size would result in reducing the energy overhead as the number of nodes increases, especially in flooding scenarios where each additional node gives rise to a multiplicative increase in transmission and receipt of the BTIM notifications.

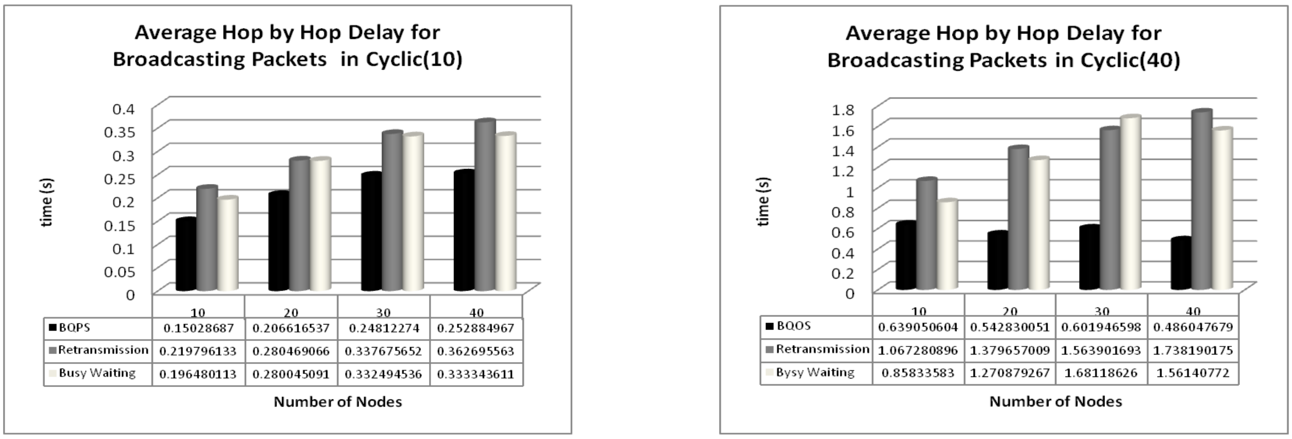
The average optimum length for BTIM window according to simulation results is approximately 4.8 ms, which deviates only 0.1 ms from that calculated in our analytical investigation.



(a) (b)

(c) (d)

Fig. 5. The impact of the BTIM window size on average energy consumption in a MANET of (a) 10, (b) 20, (c) 30 and (d) 40 nodes.

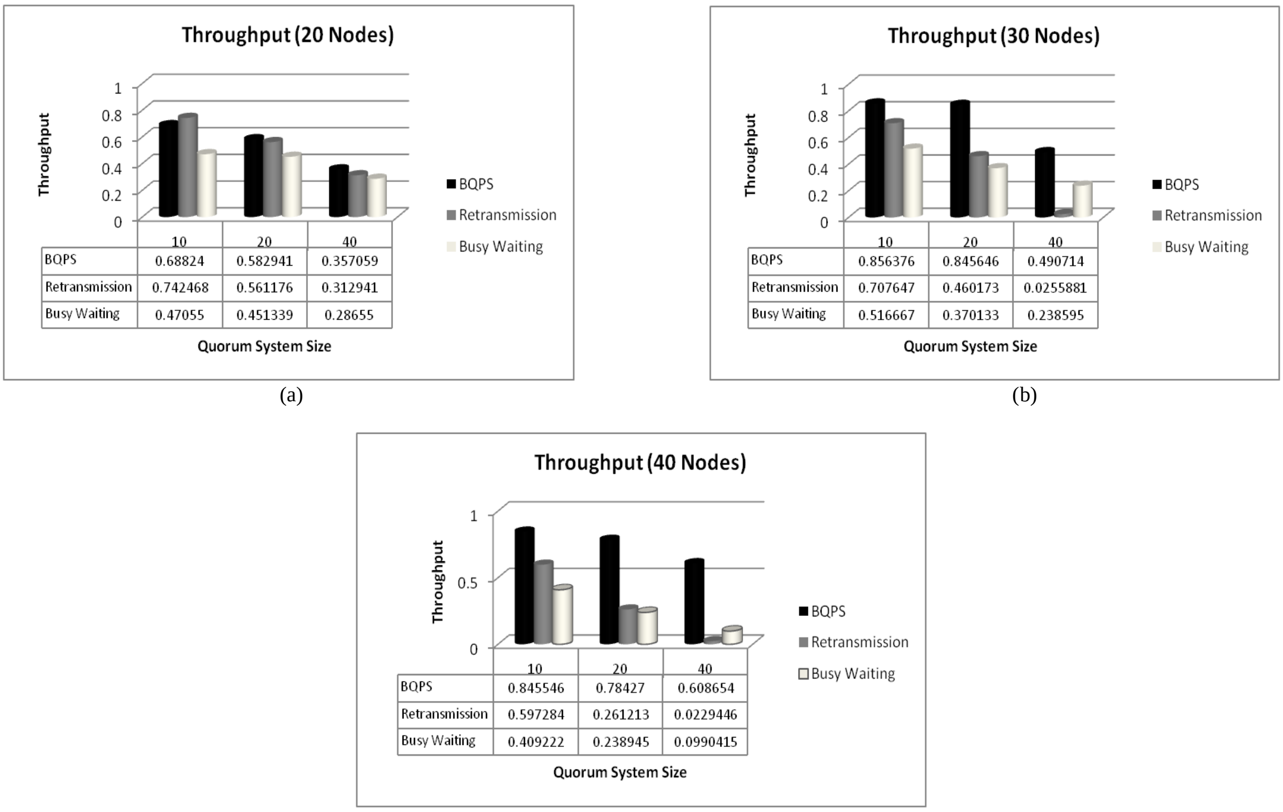


(a) (b)

Fig. 6. Average per-hop delay of broadcast packets for quorum sizes of (a) 10 and (b) 40.

In order to compare the performance of the BQPS mechanism with the "busy-waiting" and the "re-transmission-based" approaches, we measured the average per-hop delay experienced by the broadcast packets for quorum system sizes of 10 and 40. As Figure 6 depicts, for a larger quorum system size and as the network grows in scale, performance degradation in terms of increase in the one-hop latency of the broadcast messages will be much less noticeable in BQPS than that in the other two schemes.

To further demonstrate the efficiency of our approach, we also present promising results derived from another set of experiments conducted to measure the BQPS's performance in terms of network throughput. As shown in Figure 7, with the quorum system size of 40, i.e. wake-up



(a) (b)

(c)

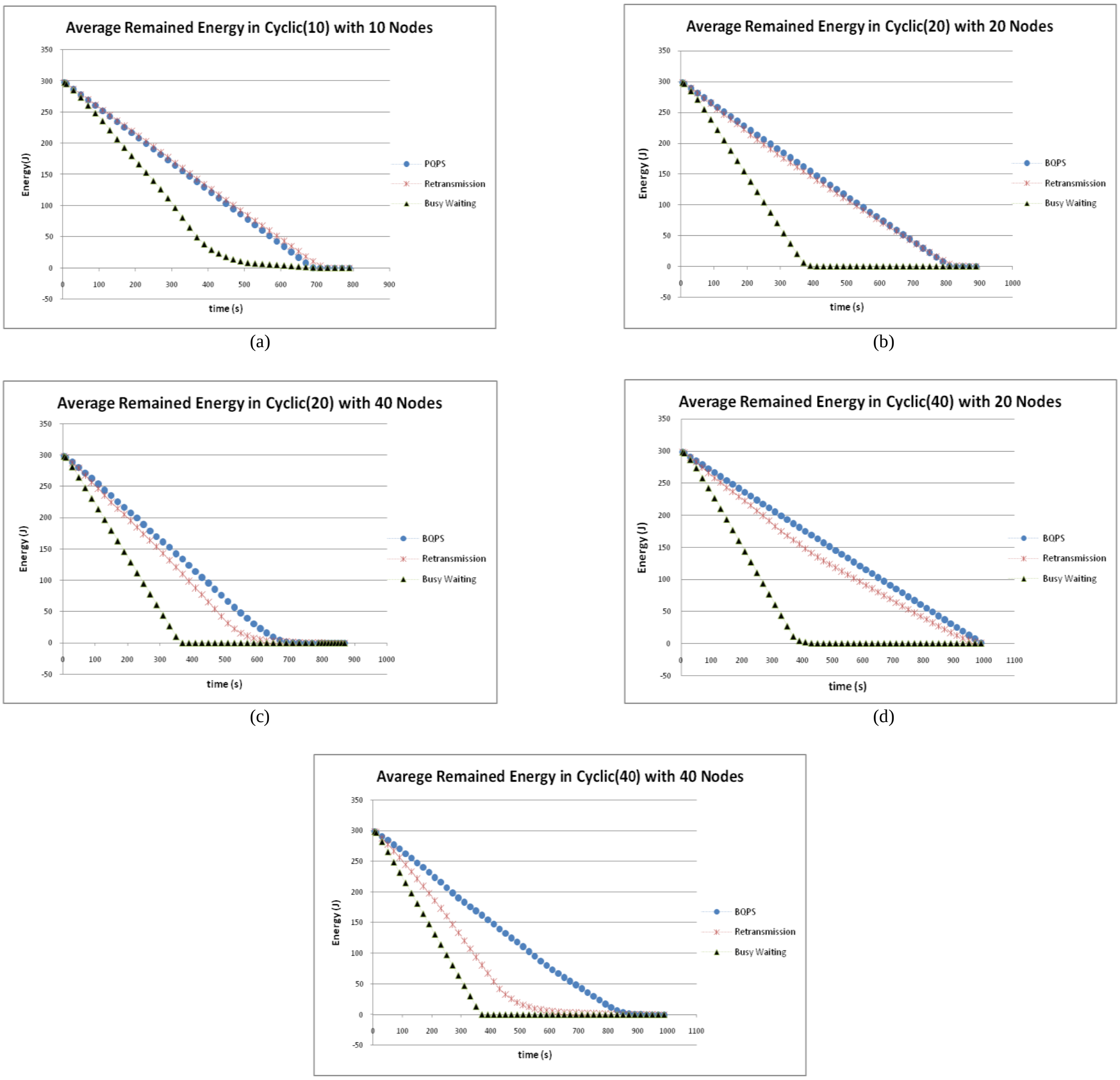
Fig. 7. Throughput in a MANET of (a) 20, (b) 30 and (c) 40 nodes.

ratio of 16%, the lower delay incurred by packets in BQPS brings in about 60% gain in network throughput comparing with the simple re-transmission mechanism. Also, BQPS, again, experiences the least degradation in throughput when it comes to schedule the nodes based on a larger quorum system size.

The results presented in Figures 7 (b) and (c) suggest that BQPS outperforms the other two methods in a network with a larger number of nodes. This can simply be attributed to the fact that the single-hop broadcast mechanism in our protocol is inherently very much independent from the number of neighboring nodes.

As it can be seen in Figures 8 (a)-(e), for a higher number of nodes or for a larger quorum system size, the energy overhead induced by BQPS is much lower than the other two methods.

The markedly poor performance of the “busy-waiting” mechanism stems from the fact that in large-scale scenarios more neighboring nodes would have to stay awake in their inactive period once they become aware of the forthcoming broadcast traffic; this is as opposed to the re-transmission approach where only the sending host is expected to remain active until the broadcast packet is successfully delivered.



(a)

(b)

(c)

(d)

(e)

Fig. 8. Average remained energy of the nodes.
(quorum size, number of nodes): (a: 10, 10); (b: 20, 20); (c: 20, 40); (d: 40, 20); (e: 40, 40).

5. Conclusion

In this paper, we proposed a new broadcasting mechanism for “asynchronous” ad-hoc networks which can also be easily incorporated into existing quorum-based power saving protocols. A special broadcast traffic indication window, viz. BTIM, is added into the beginning of the non-quorum beacon intervals and a new control packet has been introduced at the MAC layer to announce forthcoming broadcast traffic. Our approach guarantees that, if no collision occurs, the sending host would be able to notify all its neighbors by emitting notifications for the duration almost equal to the length of a single beacon interval.

Neighboring hosts, receiving these announcements, can then estimate the approximate time at which they should wake up to ensure the successful delivery of the messages. The BTIM window size has been investigated analytically in both single-hop broadcasting as well as MANET-wide flooding scenarios so as to determine the optimum value for which the average broadcast energy consumption would be minimized. Extensive simulation experiments have been conducted for performance evaluation and comparison with the prior art on the basis of the energy consumption and throughput criteria. Our measurements revealed that when the network nodes are tuned to operate with a low wake-up ratio, BQPS outperforms the existing based on “busy-waiting” or “re-transmission” mechanisms in terms of both throughput as well as the lifetime of the network.

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