Enhancing the Quality of Service in Low Duty Cycle Wireless Sensor

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ABSTRACT
Recent technologies in wireless communication have enabled the development of low-cost Wireless Sensor Networks (WSNs). Wireless Sensor Networks usually have limited energy and transmission capacity and hence turn active only when they perform sensing tasks and communications and remain dormant during idle periods. Broadcasting is one of the essential services in Wireless Sensor Networks (WSN). Broadcasting is used to propagate messages from a node or sink to all other nodes in the network. The control messages have to be broadcasted from sink to other nodes during network configuration. Also, to query the nodes about an event, message has to be broadcasted to all the nodes. The broadcasting is also used in to propagate routes to the nodes. Hence implementing an effective broadcast service which is simple, reliable and energy-efficient with less overhead is critical for the effective functioning of Wireless Sensor Networks. In this paper, the Quality of Service of the broadcasting is enhanced by reducing the message cost and the time cost in low duty-cycle WSNs. The performance degradation occurs during broadcast in low duty cycle WSN as it fails to cover the entire network within the acceptable time. This paper provides two solutions, namely, centralized dynamic and distributed solution which improves the QoS of broadcasting. The centralized dynamic solution considers diverse low duty cycle strategies. The distributed solution relies only on local information and operations for reliable and scalable broadcast service. The performance of our solution is evaluated under various network configurations. The results suggest that the quality of broadcasting in distributed solution has less time cost and message cost. In addition, it can resist the wireless loss along with considerable scalability on network size and density.

General Terms
Wireless Sensor Networks, Duty cycle, Broadcasting, Active/dormant states, Message cost, Time cost, Covering Set, Receiving Set

Keywords
QoS in sensors, Wireless sensor networks, QoS in wireless Networks

1. INTRODUCTION
Broadcasting is one of the essential services in Wireless Sensor Networks (WSN). Broadcasting is used to propagate messages from a node or sink to all other nodes in the network. The broadcasting involves propagation of data packets as well as control messages. Any node which wishes to query the network about an event has a query message that is to be broadcasted to all other nodes. The control messages have to be broadcasted from sink to other nodes during network configuration. Hence a reliable broadcast service is very important in the effective functioning of WSNs.

Two basic approaches of broadcasting are flooding and gossiping. Their basic forms are inefficient as they assume all nodes are active. If all nodes are active during the broadcast process every node can receive or forward the message. This process of assuming the nodes to be active is referred as all-node-assumption. The all-node-active assumption fails to detain the distinguishing character of energy constraint WSNs. The energy constraint sensor nodes swap between dormant and active states. During the active state, the nodes execute sensing tasks and communications and thereby dispose of considerably excessive energy. But during the dormant state the nodes remain idle consuming less energy. In this context, we define the term duty cycle as ratio between active period and full active and dormant period.

Duty cycle=active period/full active and dormant period

A low duty cycle WSN minimize the time a node spends in overhearing an unnecessary activity by placing the node in the dormant state. Hence, a low duty cycle WSN, the nodes have longer existence in the place where they are deployed for operation. In a low duty cycle WSN, where the number of nodes is small the broadcast can be enabled by waking up all the nodes through global synchronization. But it is not possible in large networks as it is difficult to provide prior knowledge about local timing information and schedules throughout the entire network. Also, the duty cycles are optimized based on the application or deployment and hence the broadcast service accepting the schedules must be a cross-layer optimization of the system.

In this paper, the quality of broadcasting is enhanced. As the nodes in a network wake up during different time intervals, a node will have to send the message to its neighboring nodes several times at different chances. This, in turn, prolongs the time necessary for a message to reach all the nodes. The performance degradation also occurs during broadcast in low duty cycle WSN as it fails to cover the entire network within the acceptable time.

This paper provides two solutions for enhancing the quality of broadcast service in low duty cycle WSNs namely centralized dynamic and distributed solution. The centralized dynamic solution is acquired from the tree formed during the broadcast process. This is applicable to diverse duty-cycle aware strategies. The distributed solution relies only on local information and operations for reliable and scalable broadcast service. The performance of our solution is evaluated under various network configurations. The results suggest that the quality of broadcasting in distributed solution has less time cost and message cost. In addition, it can resist the wireless loss along with considerable scalability on network size and density.

The remainder of this paper is organized as follows: Section 2 lists the literature survey. In Section 3, we discuss the quality of broadcast service in low duty-cycle WSNs. Section 4 brings in the centralized dynamic solution. Section 5 discusses the distributed implementation. In Section 6, we have presented extensive simulation results which are used for performance evaluation of our solution and have concluded the paper in Section 7

2. LITERATURE SURVEY

Several schemes have been proposed to address the broadcasting problem. Various modifications have been performed on the basic broadcasting approaches to accommodate the challenges in wireless environment. Smart gossip [11], which is developed from basic gossip enumerates the importance of each node to the propagating messages and adaptively adjusts gossip probability based on topology. In [12], the broadcast storm problem is solved using four approaches namely probabilistic scheme, location based scheme, distance based scheme and counter based scheme. The rebroadcasting is allowed only if the expected additional coverage is high.

Trickle, which is proposed in [13] suggests an algorithm for code propagation and maintenance in WSN. During code propagation, when a node finds that any other node has old metadata, it generates a code update. Our work is different from the above as it considers the alternating active and dormant states of the node.

There have been numerous studies exploring the low duty cycle wireless sensor network. Some of the examples are C-MAC, S-MAC, T-MAC, D-MAC. These low duty cycle protocols which focus on MAC layer has the duty cycles subject to changes based on network traffic. Y. Sun and others proposed RI-MAC [14], which is an asynchronous duty-cycle protocol, which does not require synchronization among the nodes in the network. The sender of the RI-MAC stays silent until it receives an explicit signal from the receiver announcing when to start data transmission. The PBBF suggested in [15] ensures that all nodes receive atleast one copy of the disseminated message with higher probability. The ADB proposed in [16] is asynchronous which make use of unicast to propagate message to the neighbors. Another approach, Opportunistic Flooding, proposed in [17], reduces the flooding delay and redundancy in transmission by allowing node to forward with higher probability, if the packet arrives earlier in the energy optimal tree. In [18], authors propose DSF which use multiple potential forwarding nodes at each hop depends on the wake-up schedules of forwarding nodes. TRAMA proposed in [19], uses distributed election method to determine if a node can send during a particular slot. In [20], authors solve the broadcast problem in low duty cycle WSN.

Our work differs from these approaches by considering the distinguishing character of alternating between active and dormant state of the nodes. Also our work is a cross-layer optimization of the system. We also assume that the active/dormant schedules are programmed based on the application. Our work reckons the quality of network-wide quality of service.

3. Quality of Broadcast Service

In a low duty cycle network, a node can forward the message to its neighbor only if the neighbor is awake. In addition a node that has already received the message can only forward it. Also the broadcast message should be reached to all nodes in the network. Consider a low duty cycle network as shown in the Figure 1. The sink forwards the message to the nodes 1 to 3 only if the three nodes are awake. Else the sink has to send the message to the three nodes at different instances depending on the wake-up schedules of the nodes. If there is no overlapping of the active periods of the nodes (1 to 3), the sink will have to send the message three times at dissimilar instances. In case of multiple hops for example the message to reach node 5, if the node 2 is not awake for long time the message will take longer route through node 1.

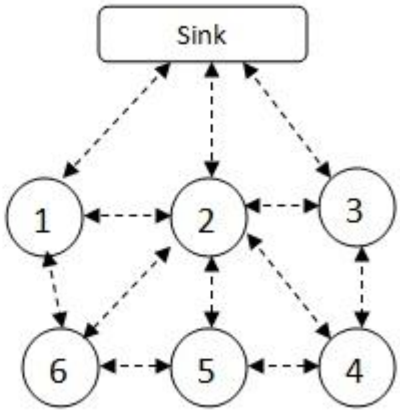

Fig. 1. An example for duty-cycle-aware broadcast. The dashed lines shows communication links and they are not always available in the presence of duty cycles

The quality of the broadcast mainly depends on message cost and time cost. The message cost which is defined as the number of times the message is sent can be minimized if there are overlapping active periods of the nodes in the tree through which the message is propagated. The time cost which is defined as the time taken for the message to cover the entire network can also be minimized by forwarding through the active nodes irrespective of the shortest path. If we denote the propagation of message as $(n_{i,} t_i)$, where the node n_i propagate the message at time t_i, then the propagation schedule can be denoted as

$$S = \{(n_1, t_1), (n_2, t_2), \dots, (n_m, t_m)\}$$

The message cost is the calculated as $|S|$ and the time cost can be calculated from $(t_0 - t_m)$, where t_0 is the starting time of propagation from node s. The combination of message cost and time cost, $f = |S| + (t_0 - t_m)$, is the focus of this paper. This can be extended to a wide range of applications by assigning different weights (w_a, w_b). For the applications that need a message to be broadcasted immediately can use small w_a with a large w_b. For the applications that use large message which does not require immediate propagation can use large w_a with a small w_b which helps in saving the message cost and the energy. The propagation schedules actually depend on the ratio of w_a/w_b and also influence the message cost and the time cost.

4. Centralized Dynamic Solution

The centralized solution is constructed on the basis of time and coverage. Consider a vertex $v_{R,t}$, where R represents the sensor nodes that have received the broadcast message at time t, i.e., the nodes in R have been covered. The set of nodes in R starts from {sink} and increase until {n}, where n is the total number of nodes. Each set in R denotes a connected sub-tree of the network from sink. The sink can be either the sink or any of the nodes in the network that acts as the source for the message. Only a few set of Rs among the 2^n sub-trees are active due to the duty cycles of the nodes. The vertex $v_{R,t}$ consists of two kinds of edges namely time edges and the propagation edges. The time edge is concerned with the case that no node in the set R is active and hence the propagation for coverage is carried out in next time slot. The propagation edge from $v_{R,t}$ to $v_{R',t'}$ correspond to the case that one or more active nodes have propagated the message and the resulting new coverage at time t' is denoted by R'. This time-space coverage vertex corresponds to the propagation sequence discussed above. In the function $f = |S| + (t_0 - t_m)$,, for the time edge we assign a weight w_b and a weight $w_a p + (t_0 - t_m)$ to each propagation edge from $v_{R,t}$ to $v_{R',t'}$, where p is the total number of nodes in the set R that propagate the message at time t.

5. Distributed Solution

Using the centralized dynamic solution, the lower bounds of message cost and time cost can be calculated. It can also be used for assessing different broadcast strategies. Practically, it very well suited for small networks with centralized entity and also for large broadcast messages with are low frequent. For large networks the centralized dynamic solution results in higher computational cost and also the complexity in obtaining the global connectivity and the active/dormant schedules. To solve these issues the distributed solution is addressed in this section.

The distributed solution focuses on the one-hop and two-hop neighbours. This reduces the computational overhead but still maintains reasonable accuracy. The global information about two-hop neighbours can be obtained by sending a simple beacon signal and this also reduces the message forwarding contentions. For a node w, we define a Covering Set, which is set of nodes that can be covered by w in one or more propagations. When a new broadcast message is received, the Covering Set is created and it is updated when the node w broadcast the message. For the node w to forward a message, the node will find out which of the neighbours are active based on the active and dormant schedules and these neighbours will be added to the Covering Set. Also when any broadcast message is received or overheard, the currently active neighbours of the message's sender is also added to the Covering Set. The Covering Set of a node gives the node's perception about its neighbours on the broadcast coverage. The centralized dynamic algorithm is modified accordingly to calculate the propagation schedule based on the Covering Set. Whenever the Covering Set is updated, the node w checks if it follows the propagation schedule. Since the Covering Set gets updated and expanded, the computational cost is lowered over time.

The Receiving Set for each node w is introduced to enhance strict coverage. The Receiving Set is defined as the set of 1-hop and 2-hop neighbours of node w that have already received the message. When a new broadcast message is received by w, the Receiving Set is created and appends the sender of this message to it. Later when the same message is received or overheard from some other neighbours, the node w appends sender into the Set, if it is not already in it. If all 1-hop neighbours are included in the Receiving Set, which ensures that all 1-hop neighbours have received this message, the node w can stop its propagation. In addition, each node will piggy back its Receiving Set along with the message. The receiving nodes updates their Receiving Set based on the piggy backed Receiving Set. A timeout is used to prevent the over-expanding of the Covering Set. The Covering Set is periodically reset to Receiving Set.

The distributed solution is summarized in Figure.2 When a node w wakes-up, it checks if there is any message arrived for it. If so it checks the message type. If it is a new broadcast message, the node w creates the Covering Set and Receiving Set and appends the sender of the message and the nodes in Receiving Set piggy backed with this message. Also the node w adds the neighbours that are presently active and are covered by the set into the Covering Set. An ACK is scheduled, if the received message targets particularly on the node w. If the received message is an ACK, the node w adds the sender of the message into Covering Set and Receiving Set. Now the node w will check its Receiving Set to know if all of its neighbours have received the message. If all neighbours are included in the Set then the node w require no further forwarding and hence can safely stop releasing the memory used for Covering Set and Receiving Set. Else the node w checks if its Covering Set follows the current propagation sequence. If not, node w re-compute the propagation schedule further and the message will be send until the timeout occurs

6. PERFORMANCE EVALUATION

The performance of the solution proposed is examined through various simulations. The two metrics used for evaluation are message cost, which is the total number of propagations and the time cost, which is the time taken to cover entire network. We have scrutinized various factors that affect the performance of the solution. We also present the results based on the based on the basic configurations adopted from [7], [8], [11], [18]. The sensing field is set to a square of 200m and the range of wireless communication is set to 10m. The number of nodes is varied between 800 and 2000. We have generated 10 topologies for each of the settings and each data point is an average of 10 different topologies. During the set-up phase, the active and dormant schedules of the nodes are developed and exchanged between neighbours

6.1 Impact of w_a/w_b ratio

The propagation sequence depends on the ratio of w_a/w_b.To investigate the impact of w_a/w_b we computed the time and message cost of diverse w_a/w_b ratios setting a small network where global knowledge is possible. The results obtained are shown in Figure.3 It has been noted that the message cost decreases and the time cost increases when the w_a/w_b increases. The propagation sequence notify that most of the messages are forwarded either when all (or most) of the uncovered 1-hop neighbours turn out to be active together or when the sender or any of its uncovered 1-hop neighbor will become dormant soon. This also depends on w_a/w_b throughout the propagation. When the ratio of w_a/w_b is

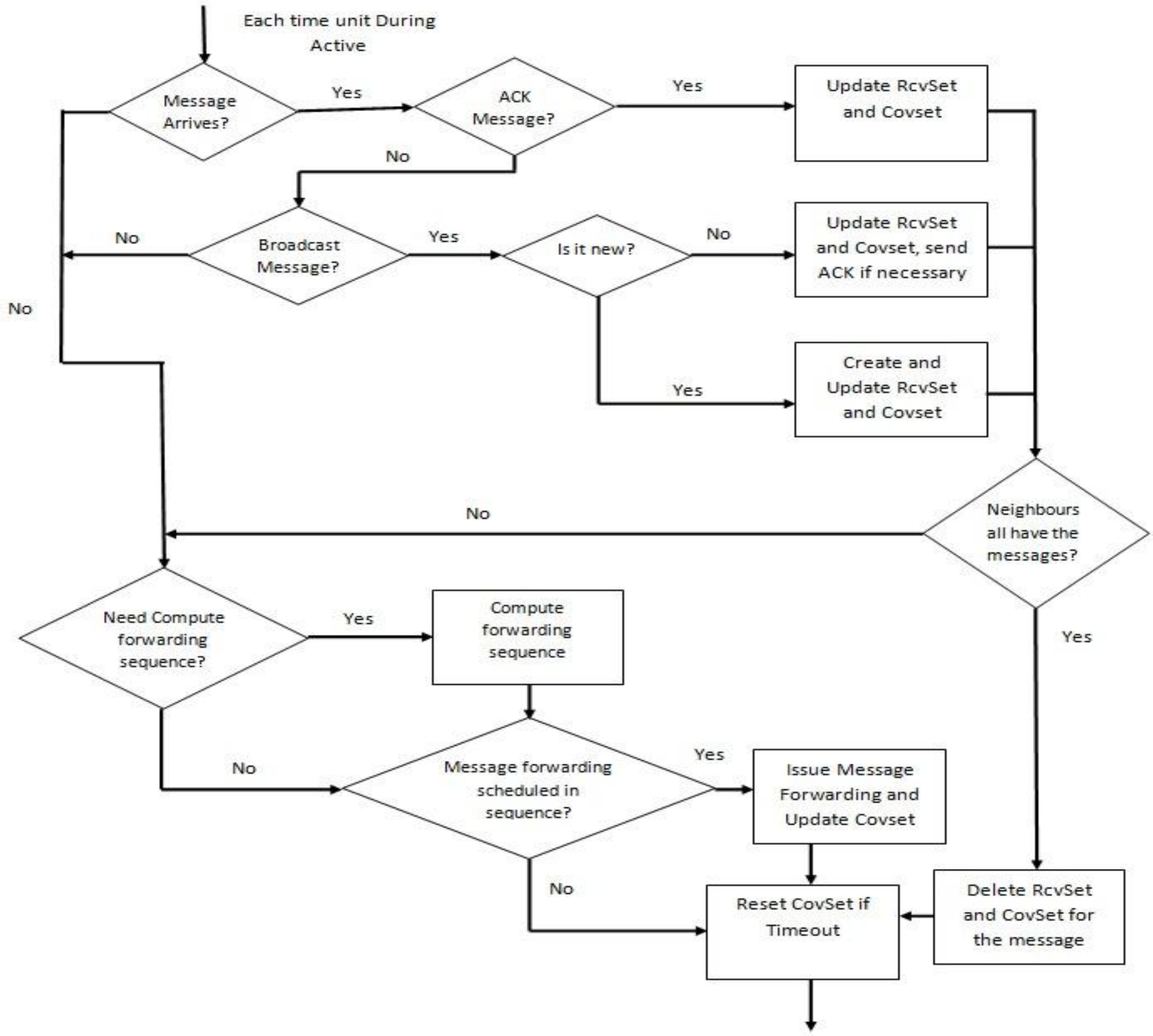

Fig 2. Operations of the distributed solution (for an active node).

around 10, the message costs and the time costs remain unchanged in spite of their low values. This implies that less message propagations are carried out in a smaller time. Hence we use w_a/w_b =10 for the distributed solution. The extreme cases like w_a (or w_b) being equal to 0 and the w_b (or w_a) being greater than 0 has been also checked. This has been resulted in the lower bounds of message cost and time cost which has been referred as message-first and time-first respectively.

6.2 Reliability to duty cycles

The solution is evaluated under different low duty cycles. The size of the network is set to 2000 nodes. The wireless loss rate is set to 20, based on the link loss for real-world sensor nodes.

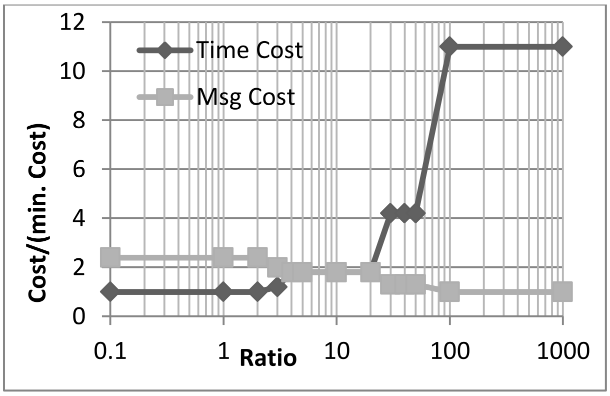

Fig 3: Impact of w_a/w_b ratio

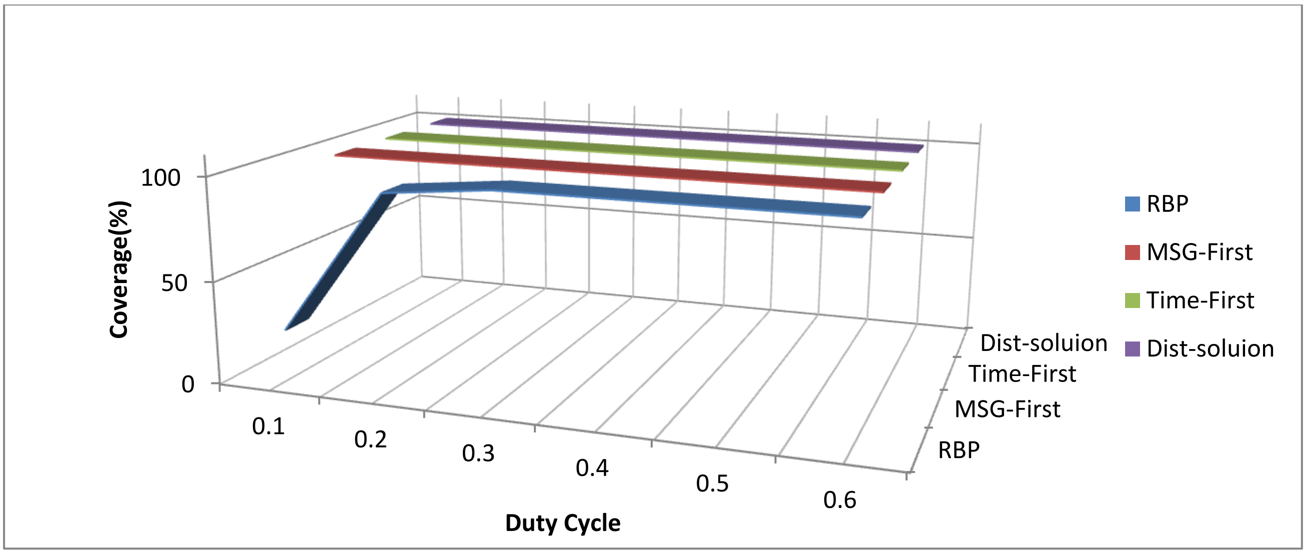

Fig 4: Reliability under different duty cycles

We also implemented RBP [7], a broadcast algorithm for Wireless Sensor Networks, for comparison. RBP is a flooding based broadcast which operates with local information. RBP aims to give reliable broadcast but it does not consider the duty cycles. In low duty cycles, RBP performs poorly and also fails to achieve its goal of reliability. The results are shown in Figure.4.The reliability of the RBP becomes undesirable, below a duty cycle of 0.5. As the Message-First of our solution which waits until all uncovered neighbours wake up together, it does not terminate in finite time. To make RBP suitable for comparison, the broadcast is reissued immediately until the required covered for reliability is achieved. This Enhanced RBP is used for comparison with time cost and message cost. This has been tabulated in Figure.5. It is seen that the distributed solution surpass the Enhanced RBP and is close to the performance of message and time costs, which is given by Message-First and Time-First, respectively. It is also seen that the Enhanced RBP performs close to the distributed solution under modest duty cycles but its performance falls drastically under low duty cycles. This shows the challenges caused by low duty cycles and the necessity to enhance the quality of broadcast in low duty cycle WSNs.

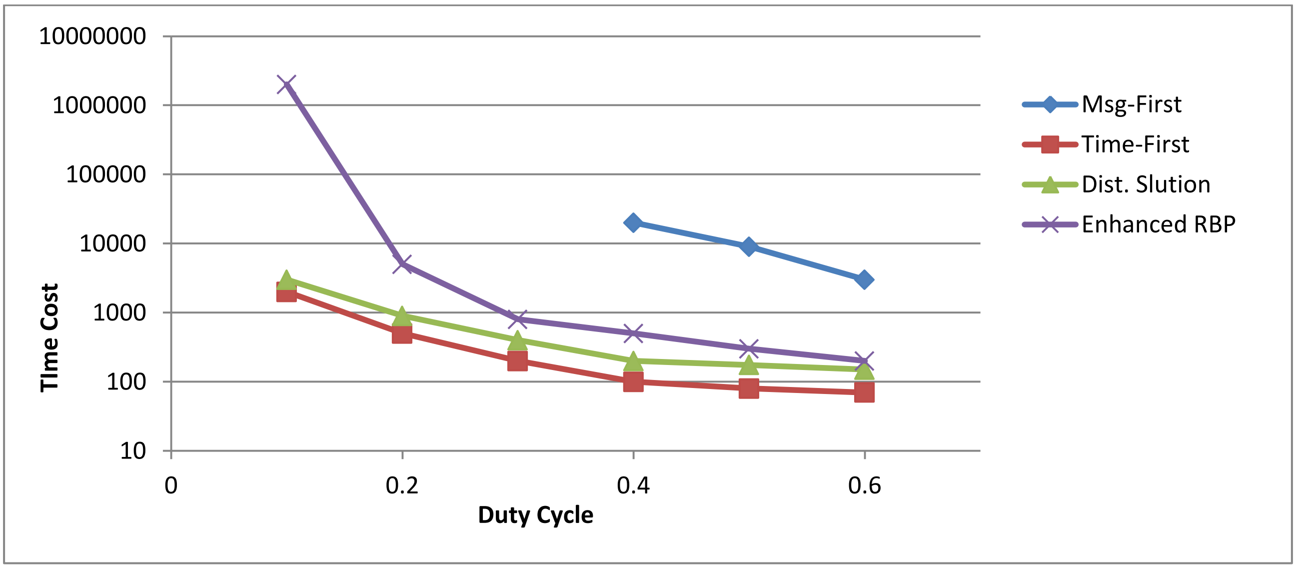

Fig 5 : Time cost under different duty cycles

The distributed solution is also self adaptive to different duty cycles. When the duty cycle increases, the distributed solution covers most of the neighbours with one forwarding, which is similar to that of message-first. When the duty cycle decreases, the distributed solution acts similar to time-first, without waiting for all nodes to wake up. This shows that the distributed solution is well suited for different duty cycles with lower bounds of message and time costs. This also shows that the existing approaches fails or performs badly in low duty cycle WSNs

7. CONCLUTIONS

In this paper, the quality of broadcast service has been discussed. We have showed that the traditional approaches fail due to their all-node-active assumption. We have presented a centralized dynamic solution which can be used for small networks and also for assessing other approaches. The distributed solution which relies on local information and operations is also implemented as an extension of centralised solution. We have examined the performance of both solutions under various network configurations and also compared our solutions with other approaches.

We are continuing our research to enhance the quality of the distributed solution. We also wish to implement the solution in the real world sensor networks and to carry out experiments to investigate the quality of its performance. We would also like to extend our solution to delay tolerant networks.

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