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# A Mobility Aware and Low Latency Mac Protocol for Mobile Wireless Sensor Network with the Improvement of S_MAC

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### *Abstract*

*There exist a lot of medium access control (MAC) protocols for wireless sensor networks. However, they consider mainly energy efficiency rather than latency which is important in delay sensitive mobile sensor networks. Therefore, a new MAC protocol called MS-MAC is proposed suitable to both stationary and mobile sensor networks. MS-MAC uses an adaptive frame structure improved for well known protocol S-MAC to overcome the performance problems caused by the packets latency in the mobile environment. The selection of monitor nodes and periodic scheduling of synchronization packets are used to predict the speed of mobile nodes, which can save the energy consumption and minimize latencies. Our studies show that under static scenarios, the MS-MAC behavior similar with MS-MAC. However, MS-MAC can increase the network throughput and reduce the latency significantly without more energy loss in comparison with S-MAC in mobile environment.*

***Keywords****: mobility aware; clusters; network latency; MAC protocol; mobile sensor networks*

## 1. Introduction

Rapid advances of wireless communication and mobile device technologies have made wireless sensor networks (WSNs) possible. WSNs, consisting of a large number of low-power, cost-effective sensor nodes, have automatically enabled to monitor the large physical environment [1-3]. In WSNs, the data generated by individual sensor nodes is generally forwarded to the sink for further processing. WSN applications include detection of natural disasters such as forest fires and volcanic activities and target tracking in the battlefields [4].The medical care application is also a critical application of WSN applications [5-6].

While many researchers have studied some important aspects of WSNs such as energy conservation [7-9], location management [10-11] , security [12], and protocol design, they have paid less attention in providing mobility management to multi-hop wireless sensor networks. Since, recently, the concept of WSN has expanded into mobile WSNs (mWSNs) in the context of pervasive ubiquitous networks [13], the mobility management in mWSNs is becoming an emerging research area. Since mWSNs are designed based on WSNs, most of the fundmental characteristics of mWSNs are similar to those of WSNs. However, there are some differences caused by mobility. The communication links can often become unreliable because mWSNs has a significantly more dynamic network topology. Consequently, sensor network applications such as medical care and disaster aid necessitate MAC protocol that supports mobility management more than the previous MAC protocol that stresses on energy efficiency [14-16]. The assumptions on static sensor nodes under the general sensor networks do not hold for these applications any more.

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Traditionally, the energy consumption is considered as the most important research issue in WSNs. S-MAC and T-MAC [17], are the representative protocols used to reduce the energy consumption in WSNs. They use the operation of low-duty-cycle to preserve the energy of the sensor nodes. By using the operation of low-Duty-cycle, sensor nodes can sleep when the nodes need not communicate with each other and reduce energy consumption. The protocols also propose a concept of virtual cluster to reduce control overhead and allow traffic-adaptive wake-up. Although these protocols address the main issues of saving energy, these protocols may lead to a long packet delay due to a sleep period, if the protocols are used in mWSNs.

The most widely used MAC protocol for sensor networks is S-MAC. S-MAC introduced a low-duty cycle operation in multi-hop wireless sensor networks, where the nodes spend most of their time in sleep mode to reduce energy consumption (Figure 1). Papers on T-MAC showed that S-MAC does not perform well with variable traffic loads. T-MAC introduced traffic-adaptive dynamic sleep and awake periods for sensor nodes. These protocols assume static networks with the focus on energy conservation. The frame time in S-MAC and T-MAC is fixed. We introduce super frame in order to synchronize mobile nodes.

In this paper, we propose a novel MS-MAC protocol to minimize the interval that the mobile sensor nodes wait for data transmission. MS-MAC has the following distinctive features. MS-MAC uses monitor nodes in each cluster for fast cluster synchronization. This watch dog node does not have a sleep period but always functions in a listen mode, which is different from a general node. Plus, MS-MAC controls the schedule of nodes by using a sleep-wakeup sequence generator that alternates the sleep-wakeup cycle on the basis of the movements of nodes, instead of fixed intervals. Finally, MS-MAC detects the movements of nodes without using hardware such as GPS that increases the complexity of the nodes.

The paper is organized into four sections. In the next section, we analyze some problems of traditional MAC protocols of wireless sensor networks such as S-MAC when used in mobile environment briefly. We present the proposed MS-MAC protocol in Section 3- Section 4 describes the simulation results and we conclude this paper in Section 5.

## 2. Analysis of Problem

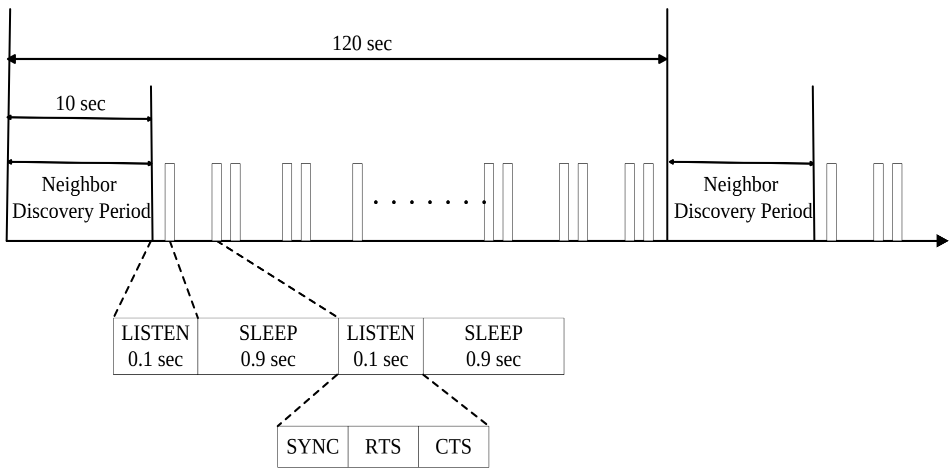



**Figure 1. S-MAC Cycle of Listen, Sleep and NDP**

Sensor nodes adopt the same sleep-wake up schedule to save energy when the nodes maintain communications between nodes in WSNs. Figure 1 shows an example of the S-MAC structure consisting of listen, sleep, and Neighbor Discovery

Protocol (NDP). Scheduling is one of the most complicated tasks in WSNs. S-MAC is a contention-based MAC protocol, specially designed for WSNs. Its main idea is that the nodes sleep and listen periodically. Frame determines the time to sleep and listen. Frame is a logical time period. Since neighboring nodes, which can communicate within one hop, can communicate within the same listen period, they must take the same schedule. In other words, neighboring nodes should be synchronized to sleep and wake up periodically. The listen period of each frame assigns a specific time for a synchronization packet, called SYNC packet. In order to maintain synchronization, each node broadcasts periodically a SYNC packet that contains its own schedule, for every 10 frames in this example. If the neighboring nodes receive SYNC messages, they will update their schedule tables, which is a time table for the scheduling communications. When a SYNC packet is interfered or corrupted, or a SYNC packet is delayed due to the busy of networks, two nodes often fail to recognize each other. In this case, the Neighbor Discovery Protocol (NDP) is allocated (for 10-second synchronization period every 120 seconds in the example in Figure 1). All nodes must keep the listen state during this NDP without falling to the sleep state.

In WSNs, a cluster is frequently used for an efficient or effective data processing. Generally, a cluster is built based on the geographical location. In other words, a cluster consists of nearby sensor nodes. The aforementioned synchronization method does not require a coherent schedule for the entire network. However, synchronization should be done within a cluster'. For communications between neighboring clusters, the nodes on the cluster borders must be aware of the listen period of the neighboring clusters, as well as the listen period of their own clusters.

S-MAC synchronization algorithm works well under static networks where the generation and break of connections do not occur frequently. Under an environment where mobile sensor nodes exist, however, it can cause as a long lag as the synchronization period that comes for 10 seconds every 120 seconds when a mobile node enters a new cluster, receives a SYNC packet, and synchronize with the new schedule. Thus, a node can be disconnected from the network up to 120 seconds waiting for synchronization. Such a packet delay can lead to a poorer performance, which can be even more serious for time critical applications.

In many sensor network applications, nodes maintain an idle state for a long time unless an event to be sensed occurs. Since the data rate is considerably low under a general sensor network, nodes do not have to be in the listening state at all times. Like S-MAC, FS- MAC also has a periodic sleep period to reduce the unnecessary listen time. In order to solve the packet delay problems due to this, MS-MAC functions with two advanced algorithms when anode moves from one cluster to another. The aforementioned problem of a packet delay grows with the process of hop. In addition, the two MAC protocols magnify the packet delay since they do not take into account the mobile sensor node environment and the neighbor discovery issues.

## 3. MS-MAC Protocol Design

We assume that a sensor network on a two-dimensional area $A$ with number of nodes $N$. The entire area $A$ is modeled as a $L \times L$ square mesh, where $L$ is the length of the network. $A$ is divided into $b^2$ meshes blocks with a side-length $\lfloor L/b \rfloor$. In each block, at least $n \geq 1$ nodes are normally distributed, where each node has the transmission radius $R$. In sum, the network is modeled as a 4-tuple $A(L,b,n,R)$. $N = b^2 n$, where $n$ is the number of nodes in each mesh block.

### 3.1. Monitor Nodes

In the proposed MS-MAC protocol, we propose the concept of monitor nodes. We define the monitor nodes as the nodes that do not sleep to preserve their energy. The nodes stay awake and in a listen mode for synchronization. The monitor nodes are selected by the nodes within a same cluster during a specific period.

We first describe the super frame of MS-MAC that is shown in Figure 2. As we can see in Figure 2, time is divided into the super frames that consist of a setup period and a steady period. During the setup period, the monitor nodes are selected. The virtual clusters are formed through neighbor discovery. This operation is processed only once during the setup period. Although the setup period may suffer from a little time overhead, the overhead can be offset by the saved energy because MS-MAC does not necessitate the NDP. The steady period consists of *F* frames, each of which includes a sleep period and a listen period. As *F* increases, general sensor nodes have more sleep time and they save more energy, while monitor nodes consume more energy. On the contrary, as *F* decreases, a relative portion of the setup period increases. It may lead to the increase of the energy consumption of the sensor nodes. An appropriate value of *F* is determined by the applications to be used.

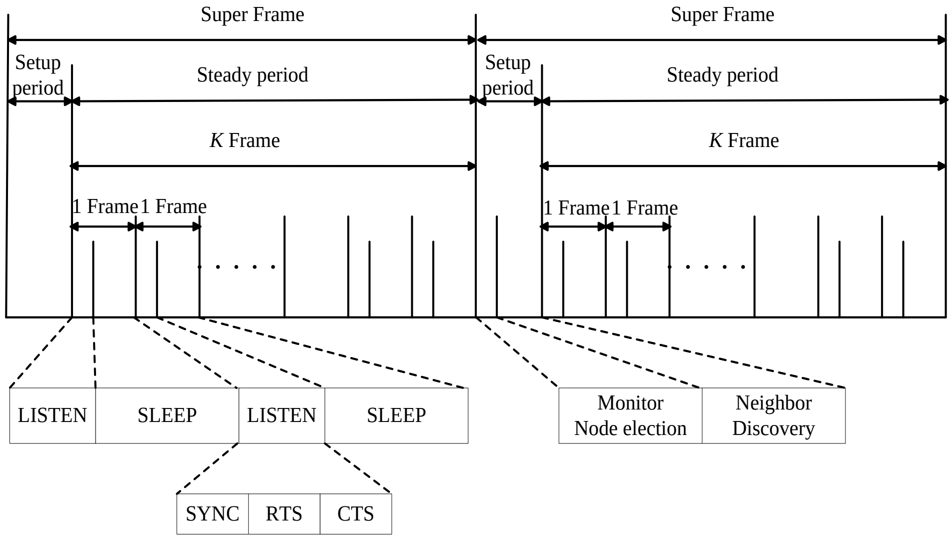



**Figure 2. MS-MAC Super Frame**

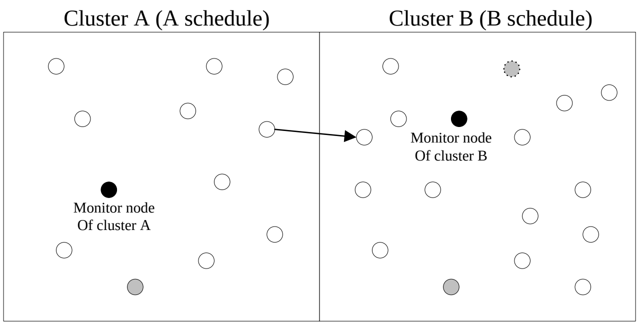
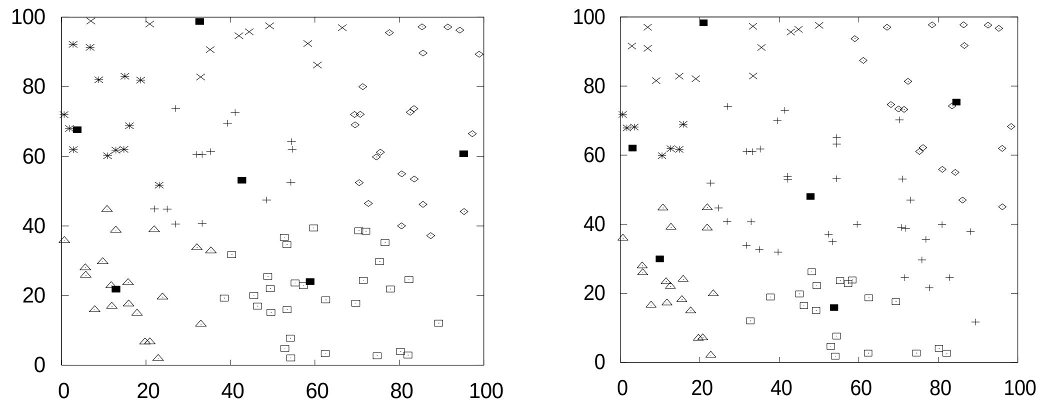



**Figure 3. Sensor Node Movement between Clusters**

Generally, sensor nodes are clustered for an efficient data processing. Figure 3 shows the example of mobile sensor nodes in two clusters. When a mobile node (*i.e.*, gray circle in Figure 3) enters a new Cluster, the first condition for the fast synchronization of the schedule is that the new cluster has nodes that can quickly receive the SYNC packet from the entered mobile node. If there is no node to receive the S'INC packet, the entered mobile node may not be associated with the new cluster until the next NDP of S-MAC comes in the worst case. We solve this problem by using monitor nodes to perform the required job.

Suppose a network with two clusters A and B in Figure 3, where the nodes within Cluster A use Schedule A, while the nodes within Cluster B use Schedule B. When a mobile node moves from Cluster A to B, the monitor node within Cluster B helps the mobile node to be associated with Cluster B as soon as possible. While general nodes follow the sleep-wakeup schedule, monitor nodes are always in the listen state. They manage the synchronization of the general sensor nodes with the sleep-wakeup schedule within the cluster. Accordingly, the monitor nodes consume more energy than other nodes. For this problem, the algorithm used in the LEACH [18, 19] protocol is modified, so that the monitor nodes are cyclically alternated. The setup period of the super frame contains the following sequence of events. First, when a cluster is constructed, all the nodes decide on whether they become the monitor nodes at this super frame. The decision is made by considering the ratio of the monitor nodes to the entire network, the time of the super frame, and the remaining energy for the nodes. A sensor node generates a random value between 0 and 1. Unless the value exceeds the threshold $Th(n)$, the sensor node decides to be a monitor node at the current super frame. The threshold $Th(n)$ is defined as following:

$$Th(n) = \begin{cases} \dfrac{R}{1 - R(t \bmod (1/R))} \times \dfrac{e_{cur}}{e_{Tot}} & \text{if } n \in A \\ 0 & \text{otherwise} \end{cases} \tag{1}$$




(a) Clusters at Time *t* (b) Clusters at Time *t*+1

**Figure 4. Formation of Virtual Clusters**

In the above equation, the initial value of $R$ is determined by the ratio of the monitor nodes to the total nodes and varies according to the applications, $t$ refers to the time of the current super frame, $e_{tot}$ refers to –the initial amount of energy, $e_{cur}$ refers to the current amount of energy, and $G$ refers to the set of the nodes that have never been the monitor nodes by the last $1/R$ super frame. This threshold turns each node to a monitor node at least once within the $1/P$ super frame. Further, as the threshold takes into account the amount of remaining energy, it prevents particular nodes from rapidly consuming their energy and improves the energy efficiency of the whole network. Once a node has become a monitor node, it helps neighbor discovery by broadcasting a SYNC packet containing its node ID, the sleep-wakeup schedule, the time of the current super frame, and the number of the total frames within the steady period. A neighboring non-monitor node, which has not received a SYNC packet from other monitor nodes, transmits the sleep-wakeup schedule of the SYNC packet to the sleep-wakeup schedule generators. It returns the response to the SYNC packet to the monitor nodes. It participates in the cluster, and starts the schedule. Figure 4 shows the generated virtual clusters at time *t* and *t*+1. Each symbol represents the nodes of the same virtual cluster. '■' represents the monitor node in each virtual cluster.

### 3.2. Periodic Use of the SYNC Packet

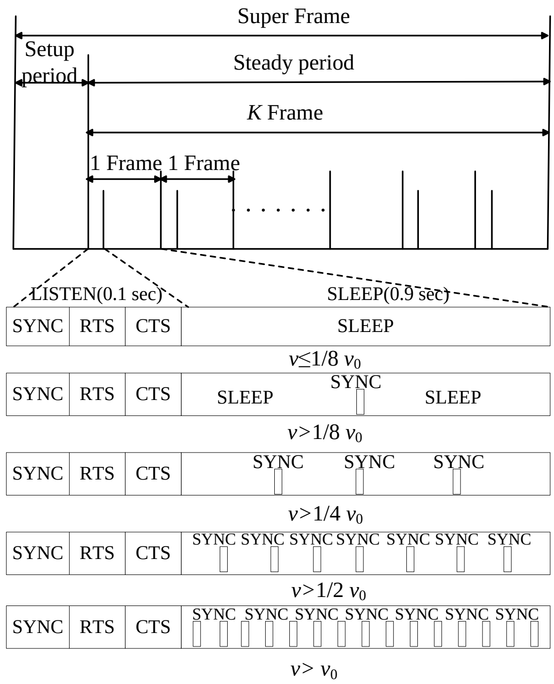



**Figure 5. Frequency of SYNC Packet During Sleep Period According to Node Speed *v***

Each sensor node determines its mobility according to the signal level of SYNC packet that it receives regularly from its neighbors. If it detects a change in the level of the SYNC packet transmitted from its neighbors, it assumes that nodes are moving and predicts the speed of the mobile nodes based on the received signal level. If the speed v of the mobile node exceeds the application-specific parameter $v_0$, the sleep-wakeup sequence generator within each node adjusts the sleep-wakeup schedule. It also broadcasts the SYNC packet regularly during the sleep period. The SYNC packet additionally includes 1 bit to differentiate the SYNC packet for the .for the monitor nodes from the previous periodic SYNC packet for synchronization. The broadcast of the SYNC packet during the sleep period gets more frequent as the change in the signal length or the speed *v* increases. Figure 5 shows the transmission of the SYNC packet according to the speed *v*. As soon as a monitor node of another cluster receives the SYNC packet transmitted from the mobile node, the monitor node sends a response packet to the mobile node. This contains the schedule of the cluster. After receiving the response, the mobile node adjusts its schedule and is associated with the cluster.

## 4. Simulation Results

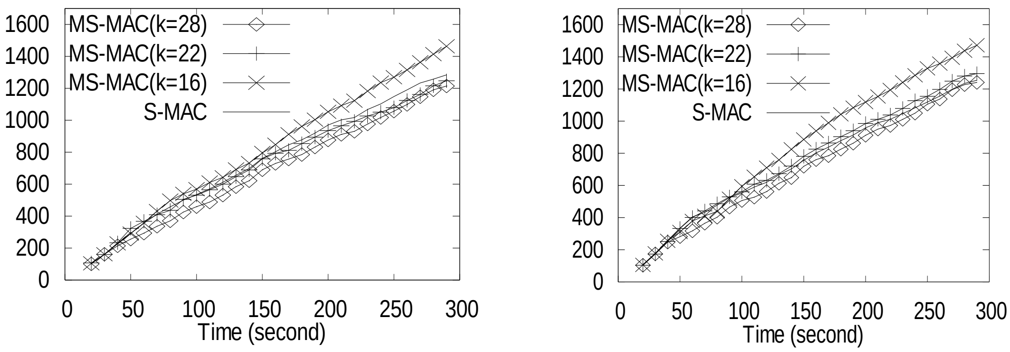
Experiments were performed using a mobile network simulation tool, the Network Simulator NS-2. The simulations aim to show how much the MS-MAC algorithm can reduce the packet delay according to the additional energy consumption compared to S-

MAC. In simulation, the number of nodes is set to 120. Each node moves freely over1000m×1000m at land. The length of each message is set to 100 bytes and the bandwidth is set to 19.2 kbps. The movement pattern of the peers follows the random waypoint model [20]. Our power consumption is based on the NS-2 default values. Power consumption on the NS-is based on the CC2420 ratio chip with 0.05 watts for a transition and 0.00005 watts for a sleep. During the 300 seconds, we simulate and compare the proposed protocol, MS-MAC with S-MAC protocol. UDP is used for the transport layer protocol. A constant bit rate (CBR) is used for the traffic source. The simulation parameters are summarized in Table 1.

**Table 1. Parameters Used in the Simulations**

| Parameter | Value |
|---|---|
| Initial energy | 100 Joules per node |
| Transmission power | 0.5 Watts |
| Receiving power | 03 Watts |
| Idle power | 0.05 Watts |
| Sleep power | 0.00005 Watts |
| Transition power | 0.05 Watts |
| Number of nodes | 120 |
| Message length | 100 bytes |
| Bandwidth | 19.2kbps |
| Reception threshold | 1.559e-11 |
| Carrier sensing threshold | 3.652e-10 |
| Ration of monitor node | 0.05 |
| S-MAC duty cycle | 10 |



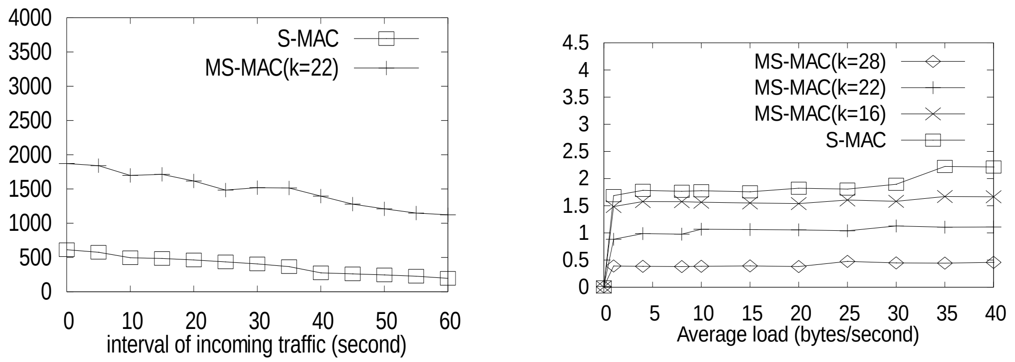

(a) Static Sensor Node Environments (b) Mobile Senor Node Environments

**Figure 6. Comparison of the Total Energy Consumption between MS-MAC and S-MAC**

Figure 6(a) shows the simulation results for the energy consumption of MS-MAC and S-MAC under the static sensor node environment. Although MS-MAC includes the setup period, it does not consume as much energy as S-MAC even in the static sensor node environment. This is because the setup period of MS-MAC uses comparatively less energy than the NDP of S-MAC. Although the setup period seems to be an overhead in terms of energy consumption, the overhead can be offset by the saved energy by eliminating the NDP. In this simulation, the parameter, *k*, is the frame number in steady period of MS-MAC. As we can see in Figure 6(a), $F$ gets smaller, the total energy consumption increases. It means that if nodes enter the setup period frequently, it may lead to much energy consumption.

Figure 6(b) shows the results for the energy consumption under the mobile sensor environments. In this case, our protocols consume slightly more energy than the results of our protocol in Figure 6(a). This is due to the additional SYNC packet of MS-MAC that is used to synchronize nodes. However, in this case, MS-MAC also shows similar performance to the S-MAC except MS-MAC (k=16).

Figure 7(a) shows the throughput of MS-MAC and S-MAC in the mobile sensor node environments. As we can see, the proposed protocol increases the throughput up to 400% over S-MAC. These results show the effectiveness of our protocol clearly. Since the monitor nodes stay awake, the newly entered nodes can synchronize early. Fast synchronization causes significant increase of the network throughput. By this simulation, we can certainly confirm that the usage of the monitor nodes is an effective way to increase network throughput.




(a) Static Sensor Node Environments (b) Mobile Senor Node Environments

**Figure 7. Comparison of the Throughput between MS-MAC and S-MAC**

Figure 7(b) shows packet delays as the traffic load increases. Average packet latency indicates that MS-MAC successfully makes cluster rapidly based on the mobile node movement speed. Although MS-MAC consumes more energy than S.MAC, MS-MAC makes a significant improvement in the packet delay.

## 5. Conclusion

In this paper, we propose a new low latency and mobility aware MAC protocol for mobile wireless sensor networks named MS-MAC. The proposed protocol can obtain an energy efficient communication while keeping high network throughput under static and mobile environments. With MS-MAC protocol, the performance problem in packet latency in the traditional MAC protocol adapted in the mobile sceneries can be solved. In order to achieve this improvement, a new mobility handling mechanism is used for the MAC layer. This mechanism adopts monitor nodes to synchronize the cluster nodes and schedule sleep-wake period of nodes based on the speed of the mobile nodes. The simulation results demonstrate that MS-MAC performs much better than S-MAC in mobile sensor node environments. The next step work is to adopt the prediction of mobility patterns to improve the performance of MS-MAC.

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