# $M^2$ANET Performance Under Variable Node Sleep Times

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***Abstract*—We investigate a new variant of ad hoc networking: a network of nodes whose sole function is to forward data in the network. This model differentiates between terminal nodes and transmission forwarding nodes in a network. We investigate the performance of the network under the condition when the forwarding nodes periodically enter the sleep state i.e., are turned off periodically. The results show the relation between the expected QoS (quality of service) and the duration of sleep time of a node (also a tradeoff between QoS and network lifetime). The higher the network node density, the lower the impact of introducing sleep state on QoS. ns2 simulation shows a $M^2$ANET network with sleeping nodes running the AODV routing protocol performing better than one running DSR for a range of node densities.**

***Keywords- MANET; transmission medium; quality of service QoS; node sleep mode.***

## I. INTRODUCTION

An ad hoc network is a collection of wireless mobile nodes forming a temporary network without the aid of any stand-alone infrastructure or centralized administration. An ad hoc network with a changing topology due to node movements is called a Mobile Ad Hoc Network (MANET) [1]. In a conventional ad hoc network, the nodes not only act as hosts but also assist in establishing connection by acting as routers that route data packets to/from other nodes in the network. One can also propose a variation of an ad hoc network where mobile nodes (blue) would be used for forwarding only in order to support communication between designated terminal nodes (red in a large circle in Figure 1).

In [2], we defined the principles of operation of a mobile network made of forwarding nodes and called it $M^2$ANET: Mobile Medium Ad Hoc Network. The network nodes form a "cloud" of communicating nodes through which all data travels, not unlike sound waves traveling through air, thus forming the medium for data transmission (propagation). In this paper we test a new hypothesis that stipulates that a reliable transmission through a mobile medium (in a $M^2$ANET) does not depend on the continuity of operation of any one network node. If our new hypothesis is true, it would have significant implications on operations of ad hoc and sensor networks. In particular, one could create a $M^2$ANET using nodes with a limited battery capacity that would operate reliably for as long as new nodes are added to the network at the same rate as other nodes run out of battery power. In another scenario one could envision a network composed of nodes that switch on and off periodically (i.e., go to sleep) and, given sufficient number of nodes, such a network would still be able to reliably transmit data. Nodes that switch on and off periodically would not only conserve battery power but also would be more difficult to locate (hack or destroy).

In Section II, we introduce $M^2$ANET and then discuss using nodes with on/off sleep states in Section III. Experiments with different numbers of nodes, different probabilities of entering sleep state, and different routing protocols are described in Sections IV and V. Finally, we present the conclusion and future work, in Section VI and Section VII, respectively.

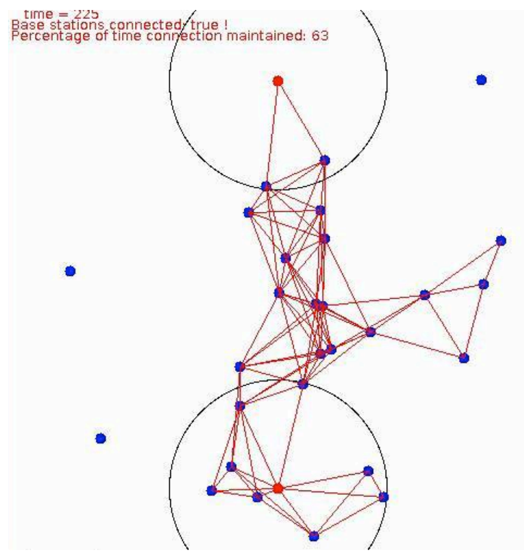


Figure 1. $M^2$ANET in operation: communication channel is established between two terminal nodes (red) using a network of mobile nodes (blue).

## II. STATE OF THE ART

Performance of a MANET is impacted by many factors including node range, node mobility, number of nodes used in a network, and the protocol used [3-7]. A good example of protocol performance evaluation is in [5]; our own tests are reported in [8].

We find it interesting that the node density issue specifically and its impact on network performance was a subject of few studies. In [9][10] authors distinguish between a physical node density versus connectivity density. The performance of the MANET depends not only on the number of mobile nodes in a particular area, but also on how likely the nodes make connections. Bettstetter and Zangl derived the expected degree of a node for $n$ nodes with range $r_0$ operating in an area $A$ [11]. Their objective was to determine the required number of nodes to achieve an "almost surely connected network", i.e., an ad hoc network with a low probability of having isolated nodes. Based on discussion in [11], we provided our own definition of normalized node density [2][8]:

$$\delta = n\, c/a, \quad (1)$$

where $n$ is the number of nodes, $c$ is the transmission area covered by a node and $a$ is the area over which the mobile network is deployed.

In our own studies we separated the network nodes into two categories: the terminal nodes and the communication nodes. In this scenario a "cloud" of communication medium nodes forms a medium through which the communication channel can be formed. With a sufficient number of nodes in the area a communication channel is formed across the mobile nodes of the $M^2$ANET allowing for designated terminal nodes to communicate. We call such a network a **M**obile **M**edium MANET, or $M^2$ANET (pronounced " *MANET square(d)*"). The main task of the $M^2$ANET is to establish communication between the terminal nodes (and not necessarily to link all other MANET nodes into a connected network). This is what makes $M^2$ANETs different from typical MANETs: as opposed to the MANET scenario described in [11], in $M^2$ANET some mobile nodes may become isolated <u>without</u> a detrimental effect on the network performance.

In [2], we showed how the different QoS criteria favour $M^2$ANET over a conventional MANET. In [8] we showed a slight advantage of AODV over DSR when used in $M^2$ANET.

## III. NETWORK OF NODES WITH VARIABLE SLEEP TIMES

The main role of the network is to establish a route and to transfer the data. In a non trivial MANET only some of the mobile nodes would be needed to maintain the route (channel) at any given time, with other nodes not participating actively in the data transfer. MANET routing protocols take care of reestablishing the route during the initial set up and in case of a node or a link failure. In a MANET, given a sufficiently dense network, any routing node can be easily replaced with other nodes forming an alternative route. The non essential nature of any routing node suggests that they form a vast cloud of nodes serving as a transmission medium.

One can take advantage of the non essential nature of any one node by allowing for a node to be switched off (or removed) and still maintaining communication through the network. The nodes can be switched off in a coordinated fashion or at random [12]. Our work is concerned with a random sleeping mechanism and, apart from an obvious scenario of evaluating network resilience in the event of a node failure, we propose a scheme in which some routing nodes are switched off and on intentionally. In addition to showing that the $M^2$ANET network can maintain its reliable operation with some of its nodes switched off, we show the tradeoff between network lifetime and quality of service QoS. In our paper QoS is defined using a single metric: the delivery ratio. The network life time is defined as the period over which there is a sufficient number of functioning nodes in a $M^2$ANET, and we assume that extending the sleep time of individual mobile nodes would conserve power and extend the network life time by a corresponding amount. At the same time, nodes in the sleep state would be unable to forward data in the network, which in turn is likely to affect network connectivity and QoS.

To establish the relation between sleep times and QoS we investigate a $M^2$ANET with $n$ mobile nodes and operating in a confined space (a rectangular region). We vary number of nodes used in the experiment and the duration of sleep time of a node. Sleep time of a node is randomly selected from a uniform distribution. The status of a node is modified periodically (e.g., every second), and $p_{on}$ designates the probability that the next state of the node would be the ON state, similar to the Randomized Independent Sleeping (RIS) introduced in [13].

Application of a $M^2$ANET with nodes with variable sleep times can be considered for many scenarios, especially when a network needs to be established quickly and without much preparation. Nodes could be dropped into a zone of interest from an aeroplane, or can spread (move away) from each terminal station. QoS can be traded for the network lifetime by adjusting the probability $p_{on}$.

## IV. JAVA SIMULATION USING NODE DISTANCE ONLY

A Java simulation of a mobile network is used with two nodes at stationary positions and the rest mobile. The mobile nodes are confined to an area bounded by a 500x500 rectangle (both the size of the bounded region and the transmitter range are defined in the same units; for the sake of the discussion below we can assume this unit distance as 1 meter). The two stationary terminal nodes shown in Figure 1 are at the opposite sides at locations (250,62) and (250, 437). The simulation is run over $10^5$ time units, with mobile nodes moving in straight lines, and randomly changing speed and direction every 25 time units. Each node can be in the on or off state, and capable of forwarding messages $p_{on}$% of the time. A connection is formed between a pair of nodes if the distance between them is less than the pre specified threshold (called range and equal to 100). We test, and visualize, for the connectivity between the terminal nodes in the network under different node densities, and for different sleep times.

The graph in Figure 2 shows the percentage of time the connectivity was maintained when (i) the nodes were switched ON only 60% of the time ($p_{on}$ = 60%), 80% of the time ($p_{on}$ = 80%), and (ii) when nodes were ON all the time ($p_{on}$ = 100%), all for different number of mobile nodes used in the simulation. The number of mobile nodes ranges from 10 to 100, for the 500x500 area and the mobile node transmission range of 100 units, corresponds to the range of normalized node density δ of 1.6 to 16 [2]. The percentage is calculated as a ratio of the total number of time units with connection criteria satisfied (path exists between two terminal nodes), to the total time. The results show that increasing the node sleep time (i.e., lowering $p_{on}$) impacts on the connectivity in the network and has a similar effect to changing the number of nodes in the network (note the translation between two functions in Fig 2). The higher the node density (or number of nodes in the network) the lower the impact on QoS of introducing the sleep state at network nodes. It should be noted that at higher node densities (e.g more than 80 nodes over the area 500x500, or δ>15) the connectivity stays at 100% whether or not the network nodes enter the sleep state, as long as it happens infrequently (Figure 3). This suggests that using nodes with variable sleep times in networks with high redundancy (δ>15) would not affect QoS while potentially extending the battery life of a node, and consequently, the life time of the entire mobile network.

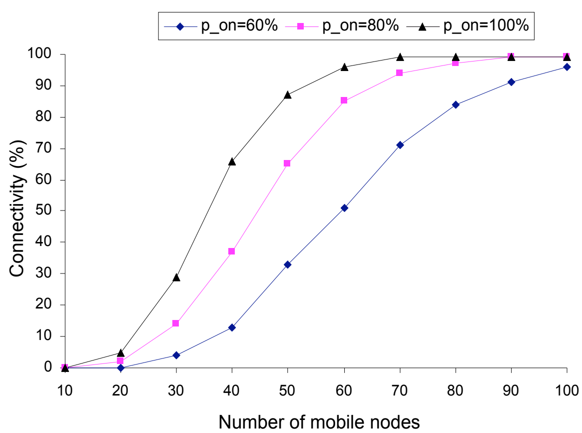


Figure 2. Comparison of M$^2$ANET with variable sleep times, $p_{on}$ at 100%, 80%, and 60% .

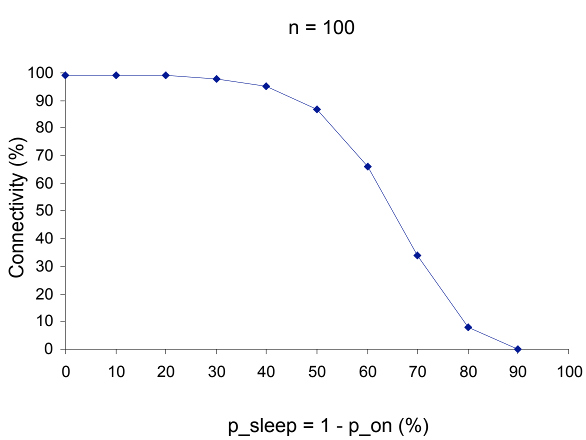


Figure 3. M$^2$ANET performance reduction at increased sleeping times.

## V. Comparison between AODV and DSR in NS2

While the Java simulation above takes into account the distance between nodes only, it does not account for the difficulties in reestablishing the routes when nodes switch on and off (i.e., enter sleep state) randomly.

We investigate the performance of two MANET protocols when used in a M$^2$ANET scenario with variable node sleep times ($p_{on}$ = 80%, ON/OFF status of a node reevaluated every 10 seconds). Each wireless mobile node uses the default 802.11 parameters and has a transmission coverage of approximately 125m x 125m. The random node mobility for the experiments is generated using a node movement generator "setdest" built into NS-2 [14]. The setdest application generates a node movement file using the random way-point algorithm. Data in the MANET are transmitted from the source to the destination node over a UDP connection at a constant bit rate (512 bytes sent every 0.1 seconds) and are generated using the NS-2 built-in CBR traffic generator. Two routing protocols are used: Ad-hoc On Demand Routing (AODV) [15] and Dynamic Source Routing (DSR) [16]. The number of nodes used in the ad-hoc network is varied from 30 to 70 (which corresponds to the normalized node density δ of 4.8 to 11.2 [2]). Each simulation is run for 50s and is repeated five times.

For performance comparison we define the delivery ratio as a ratio of the number of packets successfully received at the destination to the total number of packets sent from the source. The source is sending packets at a constant rate during the entire simulation experiment. As such the delivery ratio shows how successfully the connectivity between two nodes in a network is maintained (Figure 4). 100% packets received indicates that the connectivity was available all the time.

We attribute a slight advantage in the performance of the AODV protocol to the specifics of our experiment and to a different way the two protocols maintain and update the route information. Since we have only one source node and one destination in our network, it is only the source node that caches the route to the destination when the DSR protocol is used, while with AODV each node on the discovered route

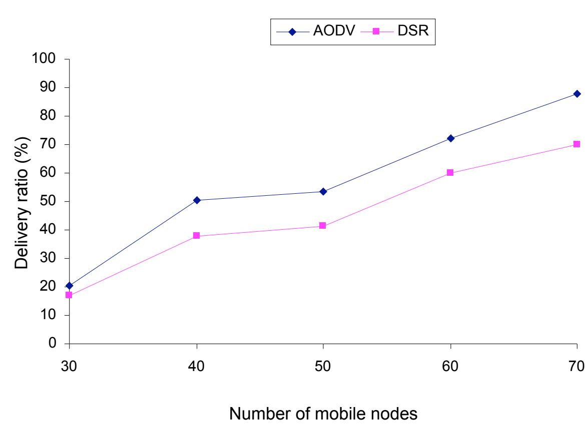


Figure 4. Comparison of AODV and DSR protocol performance for M$^2$ANET with nodes with variable sleep times, $p_{on}$ at 80%..

maintains a routing entry. When a link break occurs due to a mobile node entering the sleep state (or simply getting out of the transmission range), AODV may be able to reestablish the route faster than DSR by reusing the existing routing tables at some of the nodes (down stream from the break, or by attempting a "local repair": sending RREQ from an intermediate node), resulting in a higher delivery ratio.

## VI. CONCLUSION

We introduced and demonstrated a new view of the operation of a MANET, in which the mobile nodes form a "cloud" of transmission nodes, and act as a transmission medium. The performance metric for the $M^2$ANET is different form that of a typical network in that the transmission nodes are solely facilitating the transmission between the terminal nodes and are of no other value. The routing nodes that are not in the path of the signal between the terminal nodes do not influence the performance metric. The network can tolerate switching the routing nodes on and off periodically because the function supported by any individual node can be easily and automatically replaced by the routing protocol. The simulation shows that the performance of the network with nodes with variable sleep times is predicable: increasing the sleep time of a node has a similar effect as reducing the total number of nodes. We observed that in a network with many redundant nodes (high normalized node density $\delta$ ) introduction of variable sleep times for each network node has negligible effect on QoS and over all network performance. The simulation showed that AODV is better than DSR in a network with nodes with variable sleep times (Figure 4).

## VII. FUTURE WORK

More experimental work is required to investigate all aspects of performance of $M^2$ANETs with nodes with variable sleep times: in particular we plan to investigate the impact of the distribution of sleep times on $M^2$ANETs with different number of nodes. We also plan to investigate the performance of the $M^2$ANET theoretically, following the approach presented in [11]. We hope to introduce new routing protocols specific to $M^2$ANETs in the future. We would also like to investigate the role of the motion pattern of the mobile nodes (forming a "cloud" of transmission nodes) on $M^2$ANET performance.

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