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The Impact of Physical Conditions on Network Connectivity in Wireless Sensor Network

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***Abstract*-In Wireless Sensor Networks, end-to-end routing paths need to be established when nodes want to communicate with the desired destination. For nodes assumed to be static, many routing protocols such as Directed Diffusion have been proposed to meet this requirement efficiently. The performance of such routing protocols is relative to the given network connectivity. This paper addresses mobile sensor nodes taking into account the diversity of scattered node density and investigates how physical conditions impact on network connectivity which in turn influences routing performance. Three analysis metrics: *path availability*, *path duration*, and *inter-available path time* are proposed to quantify the impact of different physical conditions on network connectivity. Simulation results show that the network connectivity varies significantly as a function of different physical conditions.**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are a communication network normally comprising a large number of static sensor nodes. Data transmissions mainly utilize multi-hop strategies and many protocols such as Directed Diffusion [1] and GBR [2] have been proposed for routing. Their algorithms perform efficiently under the assumption that the network is fully connected and there is a contemporaneous end-to-end path between source and destination. However, the aforementioned assumptions cannot be ensured for some potential applications e.g. in battlefield operation applications, nodes are carried by moving soldiers and vehicles. As nodes become mobile, the probability of an established end-to-end path being broken increases rapidly especially when nodes move at high velocity. Additional energy and bandwidth will be consumed in order to recover the broken path. On the other hand, some sensor nodes may fail due to physical damage or power exhaust and consequently the relative node density will decrease. In this case, network partitioning i.e. all nodes in the network are not fully connected is said to occur periodically. Therefore, a significant packet delay results as no path exists between source and destination. The routing performance in terms of packet delay and routing overhead are implicitly impacted by the physical conditions.

This paper aims to further investigate the impact of physical conditions on routing performance through an evaluation of network connectivity. The physical conditions considered include node velocity and node density. In addition, the performance of network connectivity is analysed using three proposed analysis metrics: *path availability*, *path duration,* and *inter-available path time*. Those metrics are used to represent the real-time communication capability, path stability, and potential disjoint packet delay respectively. Simulation results show that the network connectivity varies significantly as a function of different physical conditions.

II. PROPOSED METRICS

A. Path availability

The *path availability* $PA(i,j)$ is defined as the fraction of time during which at least one path is available between two nodes i and j [3]. The average path availability represents the real-time communication capability of any end-to-end based routing protocol, which can be obtained by:

$$\overline{PA} = \frac{\sum_{t_1=0}^{T}\sum_{i=1}^{N}\sum_{j=i+1}^{N} PA(i,j)}{P} \tag{1}$$

where T is the evaluation time. N is the number of mobile nodes, P is the number of pairs i, j among N.

B. Path duration

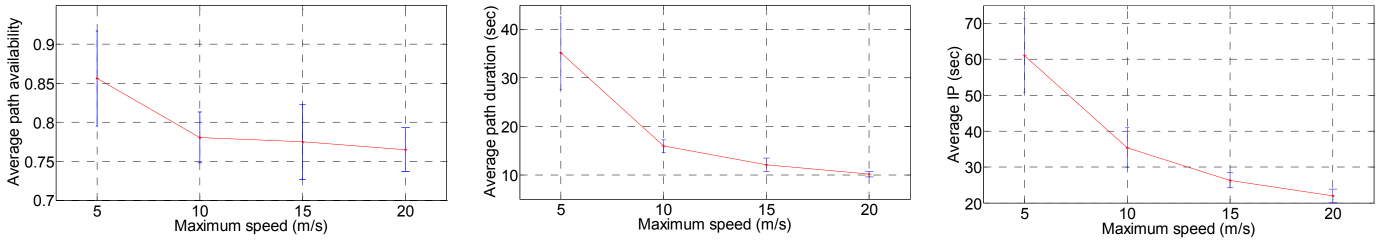
For an end-to-end routing path R = $\{n_1, n_2, \dots n_k\}$ consisting of k nodes, at time t_1, path duration is the length of the longest time interval $\{t_1, t_2\}$, t_2 is the time when one of the $(k+1)/2$ links becomes disconnected [3]. Formally,

$$PD(n_1, n_k, t_1) = \min_{1 \le z \le k-1} LD(n_z, n_{z+1}, t_1) \tag{2}$$

where $LD(n_z, n_{z+1}, t_1)$ is the link duration between nodes n_z, and n_{z+1}. Moreover, two nodes n_z, and n_{z+1} are not within the transmission range of each other at time $t_1 - \varepsilon$ and $t_2 + \varepsilon$. Where ε is any given time period and $\varepsilon > 0$. Note that $PD(n_1, n_k, t_1)$ is the shortest path duration between node n_1 and n_k at time t_1 determined by the Breadth-first search (BFS) [4]. The average path duration representative of the stability of an end-to-end routing path can then be obtained by:

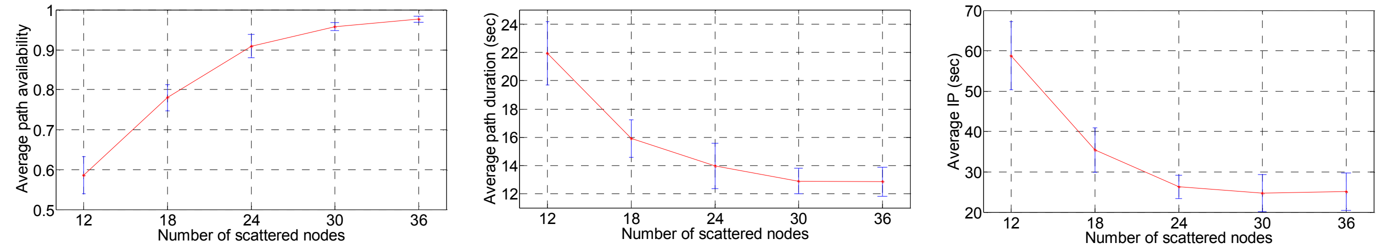
$$\overline{PD} = \frac{\sum_{t_{1=0}}^{T}\sum_{n_1}^{N}\sum_{n_k=n_1+1}^{N} PD(n_1, n_k, t_1)}{P} \tag{3}$$

where P is the number of tuples (n_1, n_k, t_1).



(a) (b) (c)

Figure 1. The average path availability, average path duration, and average inter-available path time vs. maximum speed.



(a) (b) (c)

Figure 2. The average path availability, average path duration, and average inter-available path time vs. node density.

C. Inter-available path time

The *inter-available path time* $IP(i,j)$ is defined as the time interval $\{t_1, t_2\}$ between two consecutive end-to-end path connection between nodes i and j. Moreover, two nodes i and j are connected by an end-to-end path at $t_1 - \varepsilon$ and $t_2 + \varepsilon$ for $\varepsilon > 0$. The average inter-available path time is the value of $IP(i, j)$ averaged over all existing node pairs, can be written as:

$$\overline{IP} = \frac{\sum_{t_1=0}^{T}\sum_{i=1}^{N}\sum_{j=i+1}^{N} IP(i,j)}{P} \tag{4}$$

The average inter-available path time represents potential disjoint packet delays. When a packet fails to reach its destination, it will be temporally buffered and carried by the sender until an end-to-end path is found between the sender and destination; large delay may result.

III. SIMULATION RESULTS

The network connectivity is evaluated using OMNET++ network simulator [5]. The transmission range of the nodes was 160 meters in each direction. The movement pattern of the mobile nodes is generated using Random Waypoint with a minimum speed of 0m/s, a maximum speed of 10m/s and a pause time of 20s. 18 mobile nodes moved in an area of 600m x 600m. Simulations were run for 20 simulated minutes. Each data point represents an average of 10 runs using different seeds with a corresponding confidence interval of 95%. Figure 1 and Figure 2 summarise the performance of network connectivity as a function of nodes' density and nodes' maximum speed, for the three analysis metrics. As expected, Figure 1(a) and Figure 1(b) show that the average path availability and average path duration reduce as the nodes' maximum speed varied from 5m/s to 20m/s while the average inter-available path time reduces as shown in Figure 1(c). Also, in Figure 2(a) and Figure 2(c), the average path availability decreases and the average inter-available path time increases as node density is decreased; the number of scattered nodes varied from 36 to 12. Noteworthy, in Figure 2(b), is that the average path duration improves as the node density decreases due to the edge effect (refer to [6] for detail).

IV. CONCLUSION

In this paper, three analysis metrics have been proposed to investigate the impact of physical conditions on network connectivity. The simulation results show that the network connectivity varies significantly as a function of different physical conditions. This study aims to predict the routing performance through evaluating network connectivity and therefore serves as a guideline of choosing appropriate deployment parameters for WSN.

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