Poster Abstract: Impact of Intentional Mobility in Sparse Sensor Networks

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1. INTRODUCTION

Sensor networks exploiting mobile robots have recently been proposed to provide more efficient sensing tasks in disruption tolerant networks [2, 3]. We call such a sensor network composed of mobile robots, *Mobile Sensor Network (MSN)*. Multiple robots in MSN not only cooperate to accomplish difficult or dangerous tasks that cannot be done by human beings, but their movement is also a key idea of constructing an efficient MSN. MSN has unique characteristics that are not observed in both mobile ad hoc networks and wireless sensor networks, i.e., intentional mobility, disruption or delay tolerance, and explicit collaboration. Therefore, conventional routing schemes developed for such networks would fail in this context.

In this paper, we propose a communication paradigm for MSN called *Wireless Interactive SEnsing Robot (WISER) protocol*. A major feature is a criteria of selecting between physical movement and wireless transmission at each hop. Easiness of movement are included in path decision. WISER also provides QoS guarantee and a concept of session establishment for transferring a large volume of data.

1.1 Problem Statement

We consider a *sparse* sensor network, namely, the network consists of many separate clusters, where the cluster means a group of nodes that can reach each other using multi-hop, wireless communication. All sensor nodes are mobile nodes. Each node knows its location and the location of the destination. The nodes also know the friction of the entire area in advance, or the nodes learn it after working for some periods of time.

A source node calculates an appropriate path based on known location information which is divided into three scenarios: neighbor, partial, and complete view. *Neighbor view* means each node knows only information of neighbors. Each node in *partial view* knows information of all nodes in its own cluster. *Complete view* means each node knows information of an entire network.

We consider two traffic models in sensor networks. *Continuous model* matches many real applications such as environmental and habitat monitoring, where nodes need to report sensed data periodically for a fixed period of time. *Spontaneous model* means nodes generates *single* data packet that may be warning, notice, or any sensed data employed in tracking systems, intrusion detection, etc.

2. WISER PROTOCOL

2.1 WISER/n for Neighbor View

A. Single Data Packet

Basically, a node uses greedy forwarding (GF) scheme whenever possible. If GF fails, the node moves towards the destination for a distance of its communication range (r). After its journey, the node discovers new neighbors and decides on next hop based on GF. The node moves r meters repeatedly until GF is possible. All nodes move back to their original position after they have transmitted the packet to the next hop. As shown in Fig. 1(a) (dashed lines show possible wireless communications), a packet is transmitted from source S until node C using GF. C then moves r meters, and found E and I. It selects I as the next hop because I is geographically closet to D, i.e., $|\overline{ID}| < |\overline{ED}|$.

B. Continuous Data Packets

Transmissions within a cluster use GF as employed in the single-packet case. To minimize the delay, we need to create a straight line formation called *pipeline* between partitioned clusters. First, the current node X, the node geographically closet to the destination D in the cluster, moves towards D with a distance of $|\overline{XD}|$ to survey the number of possible *helper-nodes* (m), i.e., the number of neighbors discovered during the journey. In Fig. 1(b), X discovers A, B, C, and E as four helper-nodes. X then calculates whether m is enough to construct a *standstill pipeline* (Fig. 1(c)) by using the following inequality: $m \geq |\overline{XD}|/r - 1$. If m is enough (the inequality is true), we use a minimum number of helper-nodes, $m = |\overline{XD}|/r - 1$. The total delay of the first packet is $\big(|\overline{XD}|(d + s/b)/r\big) + \big(2|\overline{XD}|/(\eta v)\big)$, where d is transmission delay, s is packet size, b is bandwidth, v is node velocity, and η is friction of the surface. The first term indicates

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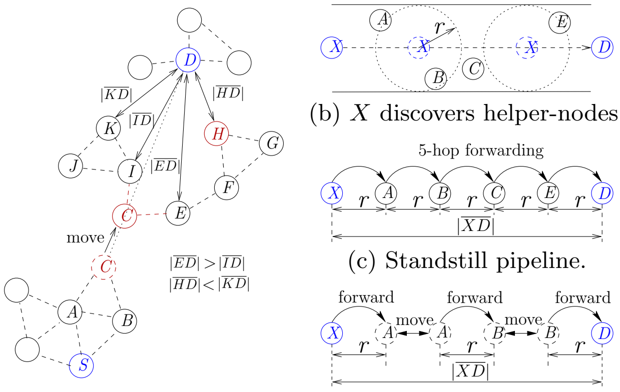
Table 1: Results averaged over ten different topologies.

	PDR			Delay (s)			Delivered message / energy (KB/J)		
	WISER/n	WISER/p	WISER/c	WISER/n	WISER/p	WISER/c	WISER/n	WISER/p	WISER/c
Scenario I	1	1	1	4.61	4.04	1.39	549.74	493.77	433.93
Scenario II	1	1	1	6.21	5.77	1.77	639.50	559.84	405.75
Scenario III	0.9923	0.9923	0.9975	4.22	3.45	0.84	500.96	334.78	433.31
Scenario IV	0.9955	0.9953	0.9997	3.94	3.60	0.37	522.83	468.62	439.85



(a) Single packet.

(b) X discovers helper-nodes.

(c) Standstill pipeline.

(d) Moving pipeline.

Figure 1: Node S and X try to send packets to D.

communication delay, while the second term shows moving delay. It costs only communication delay for the second and following packets.

If m is not enough, we introduce a *moving pipeline* (Fig. 1(d)). Helper-nodes need to move forth-and-back to get-carry-forward the packets. Minimal delay can be realized by minimizing moving distance. Therefore, each node should move forth-and-back the same distance. The total delay consists of communication delay $(m+1)(d+s/b)$, and moving delay $\left(|\overline{XD}| - (m+1)r\right)/(\eta v)$.

2.2 WISER/p for Partial View

A packet is forwarded to the node geographically closet to the destination using Dijkstra's algorithm. The total delay within a cluster is $k(d+s/b)$, where k is the number of hops. If the next hop is unavailable, a node uses the same procedures as WISER/n but it selects the next hop whose cluster is geographically closet to the destination. In Fig. 1(a), C chooses E as the next hop because H is closer to D than K, i.e., cluster $\{E, F, G, H\}$ is closer to D than cluster $\{I, J, K\}$.

2.3 WISER/c for Complete View

A node uses the same algorithm as WISER/p to forward a packet within a cluster. If the next hop is unavailable, the node uses a *greedy moving (GM)* scheme. In particular, it moves in the direction towards the next-hop node which is geographically closet to itself and closer to the destination than itself. In Fig. 1(a), C moves toward E. It stops at the edge of the next-hop node's communication range.

If there are at least two movements when a packet is sent from a source to a destination, the node uses divide-and-conquer method to achieve minimal movement. For example, if A moves toward B ($|\overline{AB}| - r$), and then E moves toward F ($|\overline{EF}| - r$), the node compares direct distance from A to F ($|\overline{AF}| - r$) with ($|\overline{AB}| - r$) + ($|\overline{EF}| - r$), and chooses the shorter one. The total delay from S to D consists of communication delay $k(d+s/b)$, and moving delay $\sum_j [(l_j - r)/(\eta v)]$, where $l_j - r$ is distance of j^{th} movement.

3. PERFORMANCE EVALUATION

We used the ns–2 simulation tool to evaluate three WISER protocols. We studied the protocols using three metrics: data packet delivery ratio (PDR), delay, and delivered message per unit energy. 50 sensors were randomly placed in a 180 m by 180 m region. Each node had fixed radio coverage of 25 m, the bandwidth of 19.2 kbps, and moved with a speed of 10 m/s. 30 random sources sent 36-byte data packet to randomly chosen destinations. Receive power dissipation (395 mW) was nearly 60% of transmit power dissipation (660 mW) [1]. Each simulation was run for 900 sec.

We simulated four scenarios as follows. *I: single packet* – each connection generated single packet. *II: single packet, single destination* – scenario I where every packet is destined to the only destination. *III: continuous packets* – each connection generated a packet every 30 sec. *IV: continuous packets, single destination* – scenario III where every packet is destined to the only destination. However, the pipelining schemes were not implemented in the simulations; we used the algorithms of single packet to deliver continuous packets.

The results in Table 1 are the values averaged over ten different topologies. Three of WISER protocols deliver 100% or nearly 100% of the originated packets. WISER/c delivers packets faster than WISER/p, which in turn does better than WISER/n because WISER/n exploits movement the most, followed by WISER/p and WISER/c, respectively. However, WISER/n achieves better energy efficiency than the others because the number of transmissions is the least.

4. CONCLUSION AND FUTURE WORKS

Unlike conventional protocols, WISER allows network partitioning and utilizes mobility of nodes as a means of data transfer. Simulation results demonstrated the benefit of physical movement in terms of delivery rate, delay, and energy efficiency. Delay guarantee can be implemented by using the equations introduced above. We plan to evaluate the full version of WISER using both simulations and experiments in the future.

5. REFERENCES

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