Impact of Mobile Sink for Wireless Sensor Networks Considering Goodput and Routing Efficiency Metrics

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***Abstract*—Sensor networks are a sensing, computing and communication infrastructure that are able to observe and respond to phenomena in the natural environment and in our physical and cyber infrastructure. The sensors themselves can range from small passive micro-sensors to larger scale, controllable weather-sensing platforms. In this work, we investigate how the sensor network performs in the case when the sink node moves. We consider as a metrics for evaluation goodput and Routing Efficiency (RE). We compare the simulation results when the sink node is mobile and stationary considering lattice topology using AODV protocol. The simulation results have shown that for the case of mobile sink, the goodput is better when the number of nodes is 16. However, when the number of nodes are 100 and 256, the goodput of mobile sink is worse than stationary sink when the values T_r is larger than 1pps. For both stationary and mobile sinks, the RE increases with the increase of number of sensor nodes, but the RE of mobile sink is better than the stationary sink.**

***Keywords*-Wireless Sensor Networks, Mobile and Stationary Sinks, Topology, Goodput, Routing Efficiency.**

I. INTRODUCTION

A Wireless Sensor Network (WSN) consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance. They are now used in many industrial and civilian application areas, including industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, healthcare applications, home automation, and traffic control.

Each node in a WSN is typically equipped with a radio transceiver or other wireless communications device, a small micro-controller, and an energy source, usually a battery. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust, although functioning ”motes” of genuine microscopic dimensions have yet to be created. The cost of sensor nodes is similarly variable, ranging from hundreds of dollars to a few pennies, depending on the size of the sensor network and the complexity required of individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and bandwidth.

There are many applications of sensor networks. For instance, in military application, the rapid deployment, self-organization, and fault-tolerance characteristics of sensor nodes make them a promising, surveillance, reconnaissance, and targeting systems. In health car, sensor nodes can be used to monitor patients and assist disabled patients. Other applications include managing inventory, monitoring product quality, and monitoring disaster areas.

Recently, there are many research work for sensor networks [1], [2], [3], [4]. In this paper, we study a particular application of WSN for event-detection and tracking. The application is based on the assumption that WSN present some degree of spatial redundancy. For instance, whenever an event happens, a certain event data is transmitted to the sink node. Because of the spatial redundancy, we can tolerate some packet loss, as long as the required detection or event-reliability holds. This reliability can be formulated as the minimum number of packets required by the sink node in order to re-construct the event field. We want to investigate the performance of WSN for different topologies considering a single mobile sink. In the large scale network, the sink node is faraway from the sensor nodes. For this reason, it is needed more energy to send the sensed data. To reduce the consumed energy of sensor node, we propose a model where the sink is mobile.

In this work, we assume a network consisting of 16, 100, 256 sensor nodes and one mobile sink, which moves continuously on an arbitrary unknown path. The position of the sink cannot be determined in advance. Sensor nodes have limited radio range, thus multi-hop communication is used in the network. We consider as a metrics for evaluation goodput and Routing Efficiency (RE). We compare the simulation results when the sink node is mobile and stationary considering lattice topology using AODV protocol. The simulation results have shown that for the case of mobile sink, the goodput is better when the number of nodes is 16. However, when the number of nodes are 100 and 256, the goodput of mobile sink is worse than stationary sink when the values T_r is larger than 1pps. For both stationary and mobile sinks, the RE increases with the increase of number of sensor nodes, but the RE of mobile sink is better than the stationary sink.

The remainder of the paper is organized as follows. In Section III, we explain the proposed network simulation model. In Section IV, we discuss the goodput and RE. In Section V, we show the simulation results. Conclusions of the paper are given in Section VI.

II. RELATED WORK

In our previous work [5], we implemented a simulation system for sensor networks considering different protocols and different propagation radio models. We did not consider the sink movement. The authors of [6] suggest a reinforcement learning algorithm for sensor nodes that they call Hybrid Learning-Enforced Time Domain Routing (HLETDR). Each node continuously learns the movement pattern of the mobile sink and statistically characterize it as a probability distribution function. Thus, sensor nodes always know in which direction they have to route messages to the sink at a given time instant. The advantage of the solution is that nodes do not need time synchronization, since they make forwarding decisions in their local time-domain. In [7], the authors consider scenarios where sensors are deployed within a circle. The authors argue that in such cases the mobile sink should follow the periphery of the network in order to optimize the energy consumption of the nodes.

However, the related work had not considered the sensor network topology and propagation radio model. In our previous work [8], we considered consumed energy in the case of mobile sink. The consumed energy of mobile sink is better than the stationary sink (about half of stationary in lattice topology) and the consumed energy of lattice topology is better than random topology.

III. PROPOSED NETWORK SIMULATION MODEL

In our WSN, every node detects the physical phenomenon and sends back to the sink node the data packets. We suppose that the sink node is more powerful than sensor nodes. In our previous work, the sink node was stationary. In this work, we consider that the sink is mobile. We analyse the performance of the network in a fixed time interval. This is the available time for the detection of the phenomenon and its value is application dependent.

Proposed network simulation model is shown in Fig. 1. For simulation system implementation, we considered modelling and network stack. In this paper, we consider that a mobile sink is moving randomly in the WSN field. In Fig. 2 is shown one pattern of mobile sink path. We evaluated the goodput and RE of AODV protocol using TwoRayGround radio model for the lattice topology.

A. Topology

For the physical layout of the WSN, two types of deployment has been studied so far: the random and the lattice deployment. In the former, nodes are supposed to be uniformly distributed, while in the latter one nodes are vertexes of particular geometric shape, e.g. a square grid, as depicted in Fig. 3. In this paper, we present results for the lattice topology only. In this case, in order to guarantee the connectedness of the network we should set the transmission range of every node to the step size, *d*, which is the minimum distance between two rows (or columns) of the grid. In fact,

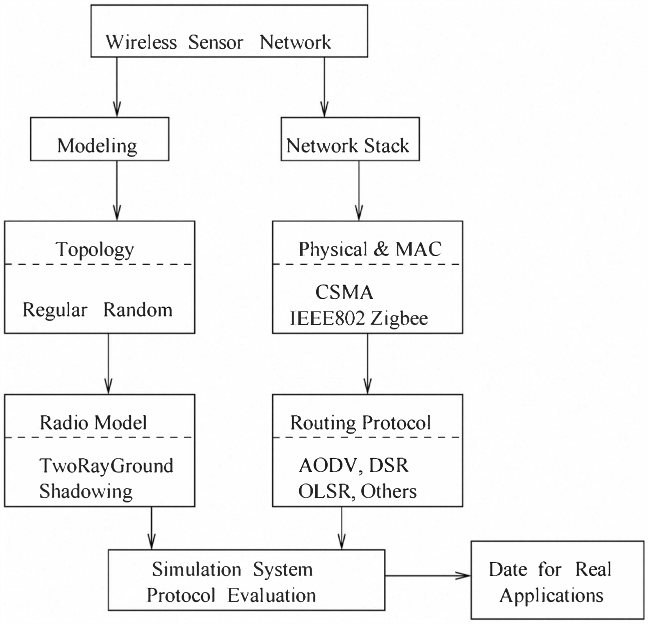

Figure 1. Network simulation model.

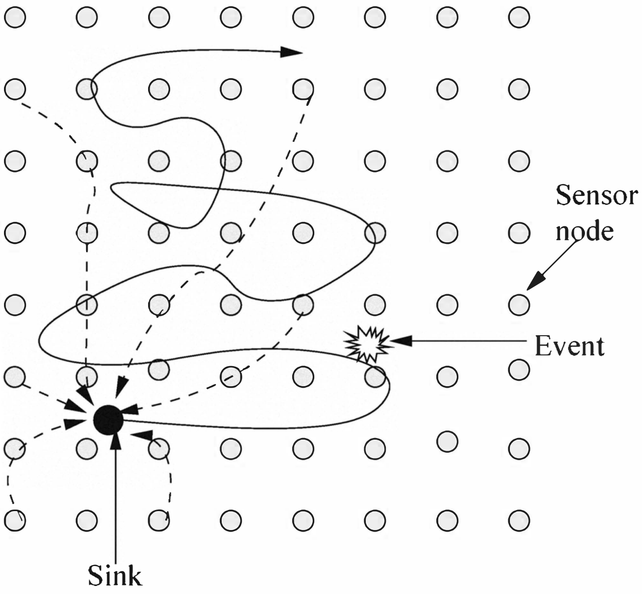

Figure 2. One pattern of mobile sink path.

by this way the number of links that every node can establish (the node degree D) is 4. Nodes at the borders have $D = 2$.

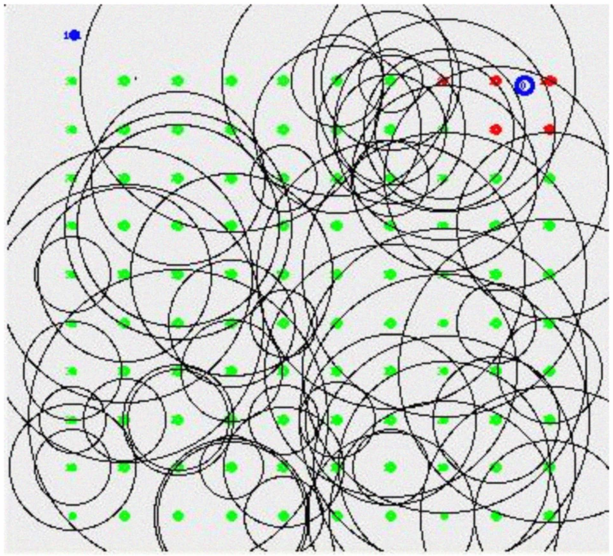

Figure 3. An example of lattice network.

B. Radio Model

In order to simulate the detection of a natural event, we used the libraries from Naval Research Laboratory (NRL) [9]. In this framework, a phenomenon is modelled as a wireless mobile node. The phenomenon node broadcasts packets with a tunable synchrony or pulse rate, which represents the period of occurrence of a generic event [1]. These libraries provide the sensor node with an alarm variable. The alarm variable is a timer variable. It turns off the sensor if no event is sensed within an alarm interval. In addition to the sensing capabilities, every sensor can establish a multi-hop communication towards the Monitoring Node (MN) by means of a particular routing protocol. This case is the opposite of the polling scheme.

We assume that the MAC protocol is the IEEE 802.11 standard. This serves to us as a baseline of comparison for other contention resolution protocols. The receiver of every sensor node is supposed to receive correctly data bits if the received power exceeds the receiver threshold, γ. This threshold depends on the hardware[2]. As reference, we select parameters values according to the features of a commercial device (MICA2 OEM). In particular, for this device, we found that for a carrier frequency of $f = 916\text{MHz}$ and a data rate of 34KBaud, we have a threshold (or receiver sensitivity) $\gamma|_{dB} = -118\text{dBm}$ [10]. The calculation of the phenomenon range is not yet optimized and the phenomenon

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[1] As a consequence, this model is for discrete events. By setting a suitable value for the pulse rate, it is possible in turn to simulate the continuous signal detection such as temperature or pressure.

[2] Other MAC factors affect the reception process, for example the Carrier Sensing Threshold (CST) and Capture Threshold (CP) of IEEE.802.11 used in Ns-2.

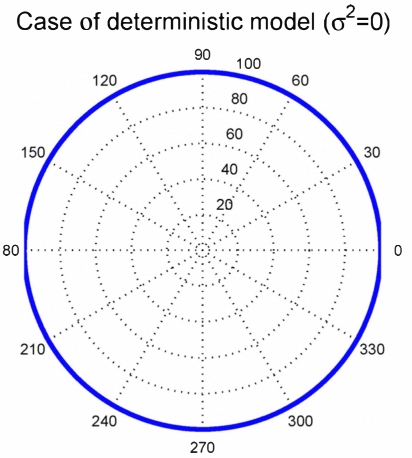

Figure 4. Transmission range of TwoRayGround model.

propagation is assumed to follow the propagation laws of the radio signals. In Fig. 4 is shown the transmission range of TwoRayGround model. In particular, the emitted power of the phenomenon is calculated according to a TwoRayGround propagation model [11].

$$P_r(d)|_{\mathrm{dB}} = \underbrace{P_t|_{\mathrm{dB}} - \beta_0 - 10\alpha \log\left(\frac{d}{d_0}\right)}_{\text{deterministic part}} + \underbrace{S_{\mathrm{dB}}}_{\text{random part}} \tag{1}$$

where β_0 is a constant. The term S_{dB} is a random variable, which accounts for random variations of the path loss. This variable is also known as log-normal shadowing, because it is supposed to be Gaussian distributed with zero mean and variance σ^2_{dB}, that is $S_{\mathrm{dB}} \sim \mathcal{N}(0, \sigma^2_{\mathrm{dB}})$. Given two nodes, if $P_r > \gamma$, where γ is the hardware-dependent threshold, the link can be established. The case of $\sigma = 0$, $\alpha = 4$, $d > d_0$ is also called the TwoRaysGround model and it is a deterministic model. where in addition to the direct ray from the transmitter towards the receiver node, a ground reflected signal is supposed to be present. Accordingly, the received power now depends also on the antenna heights and the pathloss is:

$$\beta = 10 \log\left(\frac{(4\pi d)^4 L}{G_t G_r h_t h_r \lambda^2}\right) \tag{2}$$

where h_r and h_t are the receiver and transmitter antenna heights, respectively. The formula in Eq. (2) is valid for distances $d > d_c$, that is far from the transmitting node.

Energy Model: The energy model concerns the dynamics of energy consumption of the sensor. A widely used model is as follows [12]. When the sensor transmits k bits, the radio circuitry consumes an energy of $kP_{Tx}T_B$, where P_{Tx} is the power required to transmit a bit which lasts T_B seconds. By adding the radiated power $P_t(d)$, we have:

$$E_{Tx}(k, d) = kT_B\left(P_{Tx} + P_t(d)\right).$$

Since packet reception consumes energy, by following the same reasoning, we have:

$$E(k, d) = kP_{Tx}T_B + kT_B P_t(d) + kP_{Rx}T_B \tag{3}$$

where P_{Rx} is the power required to correctly receive (demodulate and decode) one bit.

Interference: In general, in every wireless network the electromagnetic interference of neighbouring nodes is always present. The interference power decreases the Signal-to-Noise-Ratio (SNR) at the intended receiver, which will perceive a lower bit and/or packet error probability. Given a particular node, the interference power depends on how many transmitters are transmitting at the same time of the transmission of the given node. In a WSN, since the number of concurrent transmissions is low because of the low duty-cycle of sensors, we can neglect the interference. In other words, if we define duty-cycle as the fraction between the total time of all transmissions of sensor data and the total operational time of the network, we get always a value less than 0.5. In fact, the load of each sensor is $\ll 1$ because sensors transmit data only when an event is detected [12]. However, it is intuitive that in a more realistic scenario, where many phenomena trigger many events, the traffic load can be higher, and then the interference will worsen the performance.

C. *Routing Protocol*

We are aware of many proposals of routing protocols for ad-hoc networks [13]. Here, we consider AODV protocol. The AODV is an improvement of DSDV to on-demand scheme. It minimize the broadcast packet by creating route only when needed. Every node in network maintains the route information table and participate in routing table exchange. When source node wants to send data to the destination node, it first initiates route discovery process. In this process, source node broadcasts Route Request (RREQ) packet to its neighbours. Neighbour nodes which receive RREQ forward the packet to its neighbour nodes. This process continues until RREQ reach to the destination or the node who know the path to destination.

When the intermediate nodes receive RREQ, they record in their tables the address of neighbors, thereby establishing a reverse path. When the node which knows the path to destination or destination node itself receive RREQ, it send back Route Reply (RREP) packet to source node. This RREP packet is transmitted by using reverse path. When the source node receives RREP packet, it can know the path to destination node and it stores the discovered path information in its route table. This is the end of route discovery process.

Then, AODV performs route maintenance process. In route maintenance process, each node periodically transmits a Hello message to detect link breakage.

D. Event Detection and Transport

For event detection and transport, we use the data-centric model similar to [14], where the end-to-end reliability is transformed into a bounded signal distortion concept. In this model, after sensing an event, every sensor node sends sensed data towards the Monitoring Node (MN). The transport used is a UDP-like transport, i.e. there is not any guarantee on the data delivery. While this approach reduces the complexity of the transport protocol and well fit the energy and computational constraints of sensor nodes, the event-reliability can be guaranteed to some extent because of the spatial redundancy.

The sensor node transmits data packets reporting the details of the detected event at a certain transmission rate[3]. The setting of this parameter, T_r, depends on several factors, as the quantization step of sensors, the type of phenomenon, and the desired level of distortion perceived at the MN. In [15], the authors used this T_r as a control parameter of the overall system. For example, if we refer to event-reliability as the minimum number of packets required at sink in order to reliably detect the event, then whenever the sink receives a number of packets less than the event-reliability, it can instruct sensor nodes to use a higher T_r. This instruction is piggy-backed in dedicated packets from the MN.

This system can be considered as a control system, as shown in Fig. 5, with the target event-reliability as input variable and the actual event-reliability as output parameter. The target event-reliability is transformed into an initial T_r^0. The control loop has the output event-reliability as input, and on the basis of a particular non-linear function $f(\cdot)$, T_r is accordingly changed. We do not implement the entire control system, but only a simplified version of it. For instance, we vary T_r and observe the behaviour of the system in terms of the mean number of received packets. In other words, we open the control loop and analyse the forward chain only.

IV. Performance Metrics

In this paper, we evaluated the performance of the proposed model with two performance metrics: goodput and RE. The goodput is defined at the sink, and it is the received packet rate divided by the sent packets rate. Thus:

$$G(\tau) = \frac{N_r(\tau)}{N_s(\tau)} \tag{4}$$

where $N_r(\tau)$ is the number of received packet at the sink, and the $N_s(\tau)$ is the number of packets sent by sensor nodes which detected the phenomenon. Note that the event-reliability is defined as $G_R = \frac{N_r(\tau)}{R(\tau)}$, where R is the required number of packets or data in a time interval of τ seconds.

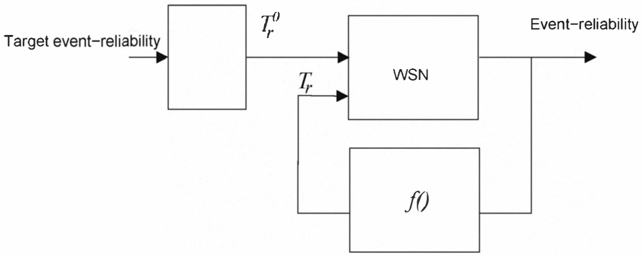

Figure 5. Representation of the transport based on the event-reliability.

We consider that after a sensor node detects the physical phenomenon, it sends the packets to the sink node via a routing protocol. The ability for transmitting packets for different protocols is different. Also, the RE of a protocol is affected by many network parameters such as wireless transmission radio model, network topology, and transmission frequency [4]. In order to compare the performance of different protocols, we consider the same simulation environment. For our system, we used TwoRayGround radio model and the network topology is regular [12]. The RE is defined at the sink, and it is the received packet rate divided by the sent packets rate. Thus:

$$RE(\tau) = \frac{N_{sent}(\tau)}{N_{routing}(\tau)} \tag{5}$$

where $N_{routing}(\tau)$ is the number of sent packets by routing protocol, and $N_{sent}(\tau)$ is the number of sent packets by sensor nodes which detect the phenomenon.

V. Simulation Results

In this section, we present the simulation results of our proposed WSN. We simulated the network by means of NS-2 simulator, with the support of NRL libraries[4].

In Tables I and II, we summarise the values of parameters used in our WSN. Let us note that the power values concern the power required to transmit and receive one bit, respectively. They do not refer to the radiated power at all. This is also the energy model implemented in the widely used NS-2 simulator.

In this work, we simulated two patterns considering stationary sink and mobile sink. For AODV routing protocol, the sample averages of Eqs. (4) and Eqs. (5) are computed over 20 simulation runs, and they are plotted from Fig. 6 to Fig. 9.

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[3] Note that in the case of discrete event, this scheme is a simple packet repetition scheme.

[4] Since the number of scheduler events within a simulated WSN can be very high, we applied a patch against the scheduler module of NS-2 in order to speed up the simulation time [15].

Table I
TOPOLOGY SETTINGS.

Lattice	
Step	$d = \frac{L}{\sqrt{N}-1}$ m
Service Area Size	$L^2 = (800\text{x}800)\text{m}^2$
Number of Nodes	$N = 16, 100, 256$
Transmission Range	$r_0 = d$
Random	
Density(nodes/m^2)	$\rho \in \{25 \cdot 10^{-6}, 2 \cdot 10^{-4}\}$
Transmission Range(m)	$r_0 = 180$

Table II
RADIO MODEL AND SYSTEM PARAMETERS.

Radio Model Parameters	
Path Loss Coefficient	$\alpha = 2.7$
Variance	$\sigma^2_{\text{dB}} = 16\text{dB}$
Carrier Frequency	916MHz
Antenna	omni
Threshold (Sensitivity)	$\gamma = -118\text{dB}$
Other Parameters	
Reporting Frequency	$T_r = [0.1, 1000]\text{pps}^1$
Interface Queue Size	50 packets
UDP Packet Size	100 bytes
Detection Interval τ	30s

[1] packet per seconds

The goodput of stationary and mobile sink are plotted in Fig. 6 and Fig. 7, respectively. We found that the goodput of mobile sink is better than stationary sink in case of 16 nodes and the goodput of mobile sink has a stable value when the T_r increased. However, when the number of nodes is increased the goodput of mobile sink is worse than stationary sink. For low values of T_r, the network is uncongested (just 30 data packets). From a particular value of T_r, the packet delivery rate drops abruptly. We have reached the network capacity. From this point on, increasing T_r does not ameliorate the packet delivery rate and $N_r(\tau)$ is roughly constant.

In Fig. 8 and Fig. 9, are shown the average value of RE using TwoRayGround model and AODV in case of stationary and mobile sink, respectively. The RE is an increasing function of T_r, because as T_r increases, the number of sent packet by sensing node is higher than the number of packets used by routing protocol. It should be noted that when the number of sensor nodes is increased, then the number of routes is increased, thus the searching time to find a route also is increased. When the number of nodes is 256, the RE is the worst in our simulation. The simulation results for the case of mobile sink are shown in Fig. 9. We found that the RE of mobile sink is better than in case of stationary sink.The explanation of this effect is not simple, because it is intermingled with the dynamics of MAC and routing protocol. However, intuitively we can say that the on-demand routing protocols are affected by the presence of the mobile sink.

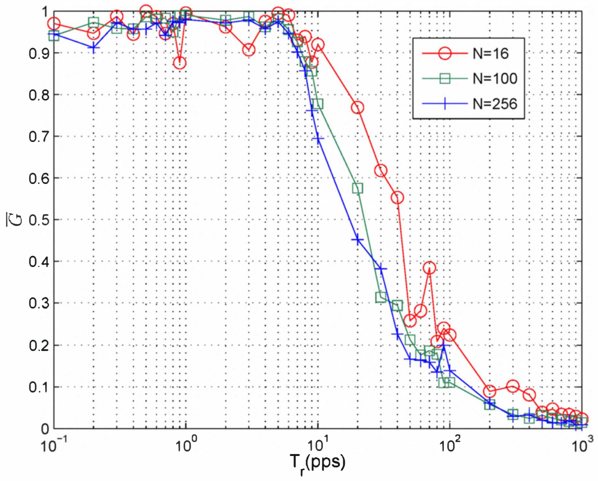

Figure 6. Goodput for stationary sink.

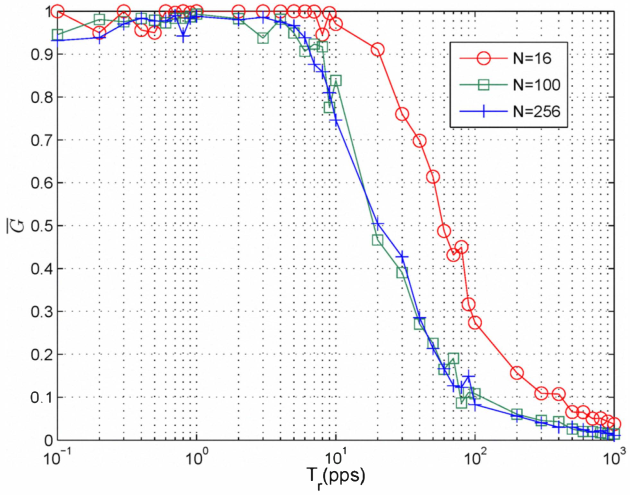

Figure 7. Goodput for mobile sink.

VI. CONCLUSIONS

In this paper, we presented the simulation results of WSN with stationary and mobile sinks considering lattice topology and AODV protocol. We used the goodput and RE metrics to measure the sensor network performance. From the simulation results, we conclude as follows.

- In case of mobile sink, the goodput is better when the number of nodes is 16, however, when the number of nodes are 100 and 256, the goodput of mobile sink is worse than stationary sink when the values T_r is larger than 1pps.
- For both the stationary and mobile sinks, the RE increases with the increase of number of sensor nodes.
- The RE of mobile sink is better than stationary sink.

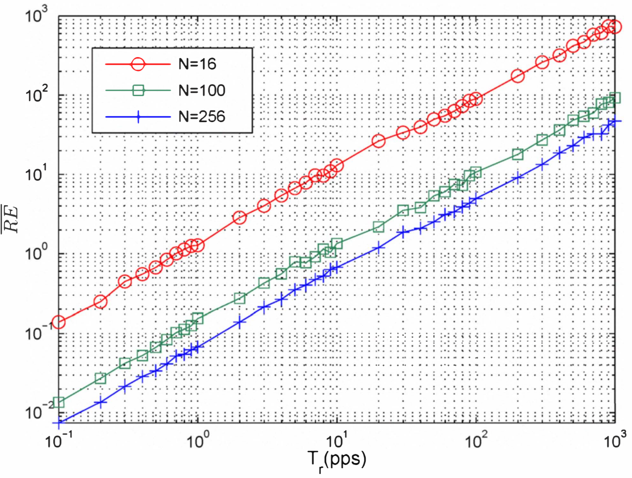

Figure 8. RE for stationary sink.

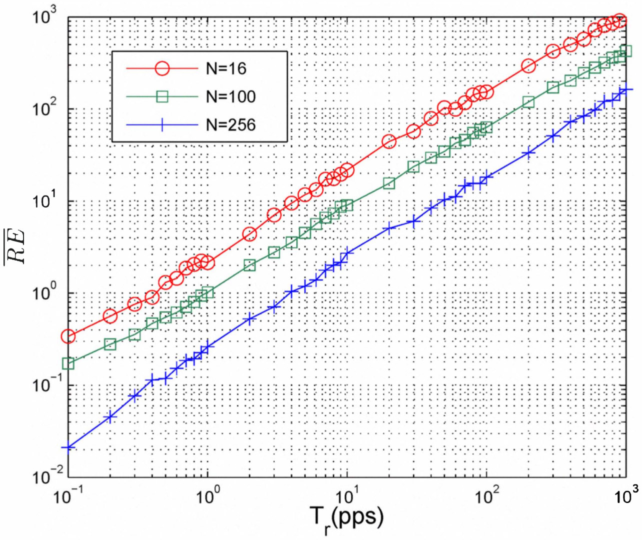

Figure 9. RE for mobile sink.

In the future, we would like to carry out more extensive simulations for multi-mobile sinks. We also would like to consider the case of special movement path.

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