

PERFORMANCE EVALUATION OF WIRELESS SENSOR NETWORKS FOR MOBILE EVENT AND MOBILE SINK

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Extending lifetime and energy efficiency are important objectives and challenges in Wireless Sensor Networks (WSNs). In large scale WSNs, when the nodes are near to the sink they consume much more energy than the nodes far from the sink. In our previous work, we considered that the sink node was stationary and only event node was moving in the observation field. In this work, we consider both cases when the sink node and event node are moving. For the simulations, we use TwoRayGround and Shadowing radio models, lattice topology and AODV protocol. We compare the simulation results for the cases when the sink node and event node are mobile and stationary. The simulation results have shown that the goodput of TwoRayGround is better than Shadowing in case of mobile event, but the depletion of Shadowing is better than TwoRayGround in case of mobile event. The goodput in case of mobile sink is better than stationary sink when the transmission rate is lower than 10pps. For TwoRayGround radio model, the depletion in case of mobile sink is better than stationary sink when the number of nodes is increased.

Keywords: WSNs, Mobile Event, Mobile Sink, Goodput, Depletion

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1 Introduction

Recent technological advances have enabled distributed information gathering from a given location or region by deploying a large number of network tiny micro-sensors, which are low-power devices equipped with programmable computing, multiple sensing, and communication capability. Micro-sensor systems enable the reliable monitoring and control of a variety of applications. Such sensor nodes networked by wireless radio have revolutionized remote monitoring applications because of their ease of deployment ad hoc connectivity, and cost effectiveness. A wireless sensor network is typically a collection of tiny disposable devices with sensors embedded in them. These devices, referred to as sensor nodes, are used to collect physical parameters such as light intensity, sound and temperature from the environment where they are deployed. Each node in a sensor network includes a sensing module, a microprocessor to convert the sensor signals into a sensor reading understandable by a user, a wireless interface to exchange sensor readings with other nodes lying within its radio range, a memory to temporarily hold sensor data, and a small battery to run the device. Wireless sensors typically have a low transmission data rate. The small size of these nodes limits the size of the battery or the total power available with each sensor node. The low cost of sensor nodes makes it feasible to have a network of hundreds or thousands of these wireless sensors [1][2].

In general, the event and sink are stationary, but in some cases, the event may move. For example, an event can happen on the robot or in a moving car. We consider that a single mobile event is deployed in a sparsely connected network.

In [3], we evaluated the performance of WSN using different radio propagation models, topologies and protocols. In [4], we evaluated the performance of a WSNs considering only mobile event.

In this paper, we consider both cases: mobile sink and mobile event. In the large scale network, the sink node may be faraway from the sensor nodes, thus the sensor nodes spend more energy to send the sensed data. To reduce the consumed energy of sensor node we proposed the mobile sink for the large scale network. To investigate the impact of mobile sink and mobile event, we generated WSNs with different number of nodes and carried out extensive simulations.

The remainder of the paper is organized as follows. In Section 2, we explain the proposed network simulation model. In Section 3, we discuss the goodput and consumed energy concepts. In Section 4, we show the simulation results. Conclusions of this paper are given in Section 5.

2 Proposed Network Simulation Model

In our WSNs model, every node detects the physical phenomenon and sends back to the sink node data packets. We suppose that the sink node is more powerful than sensor nodes. This model can be used for remote monitoring of hazard or inaccessible areas [5]. We analyze the performance of the network in a fixed time interval, τ . This can be considered as the available time for the detection of the phenomenon and its value is application dependent. In this paper, we consider that a mobile sink or a mobile event are moving randomly in the WSN field. In Fig. 1 is shown one pattern of sink movement path. We implemented a simulation system for WSNs considering mobile event and mobile sink using ns-2. We evaluated the goodput

and consumed energy of AODV protocol using TwoRayGround and Shadowing propagation model in case of the lattice topology. Proposed network simulation model is shown in Fig. 2.

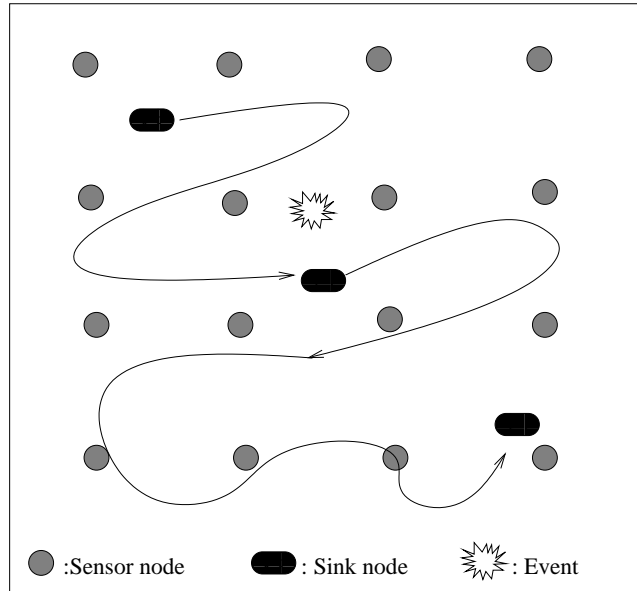


Fig. 1. One pattern of sink movement path.

2.1 Topology

For the physical layout of the WSNs, two types of deployment has been studied so far: the random and the lattice deployment. In the former, nodes are supposed to be randomly distributed, while in the latter nodes are vertexes of particular geometric shape, e.g. a square grid. For space constraints, we present results for the square grid 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, by this way the number of links that every node can establish, a.k.a the node degree is $D = 4$. By using Cooper's theorem [6] along with some power control techniques, one could use also $D = 2^a$. However, we assume all nodes to be equal and then the degree is fixed to 4. Nodes at the borders have $D = 2$. In Fig. 3 and Fig. 4 are shown the regular and random topologies.

2.2 Routing Protocols

We are aware of many routing protocols for ad-hoc networks such as Ad-hoc On-demand Distance Vector (AODV), Dynamic Source Routing (DSR) and Optimized Link State Routing (OLSR). In this work, we use AODV protocol [7]. 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 should maintain route information table and participate in routing

^aBy using the theorem in [6], we can say that a simple 2 regular network [3] is almost surely strongly 2 connected.

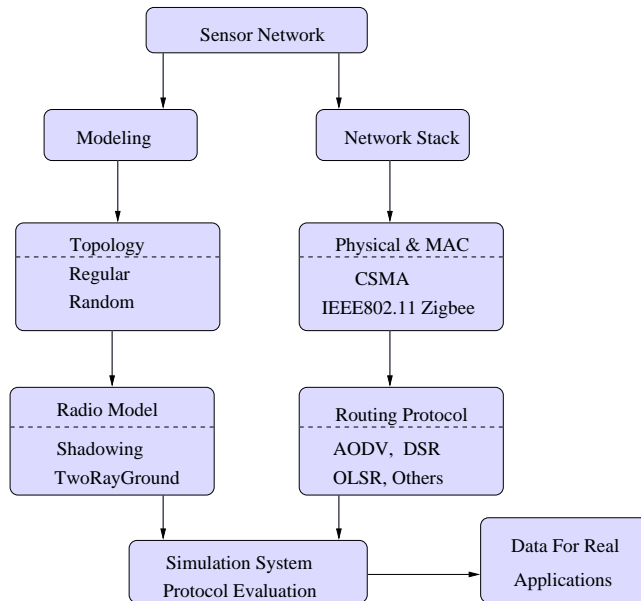


Fig. 2. Proposed network simulation model.

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 neighbors. Neighbor nodes which receive RREQ forward the packet to its neighbor nodes. This process continues until RREQ reach to the destination or the node who knows the path to destination. When the intermediate nodes receive RREQ, they record in their tables the address of neighbors, thereby establishing a reverse path. The node which knows the path to destination sends 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 the link breakage.

2.3 Propagation Radio Model

In order to simulate the detection of a natural event, we used the libraries from Naval Research Laboratory (NRL) [8]. In this framework, a phenomenon is modeled 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^b. 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.

^bAs 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.

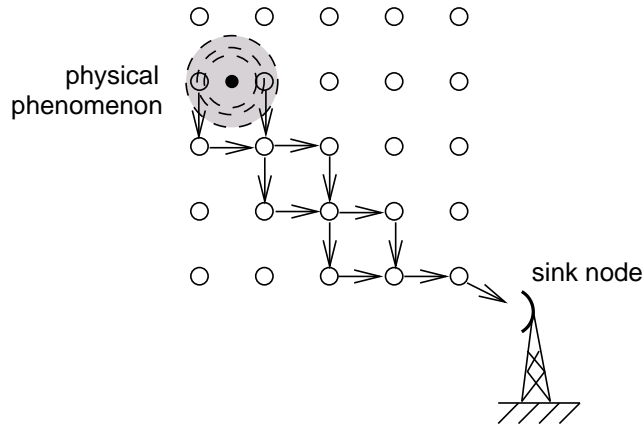


Fig. 3. Regular topology.

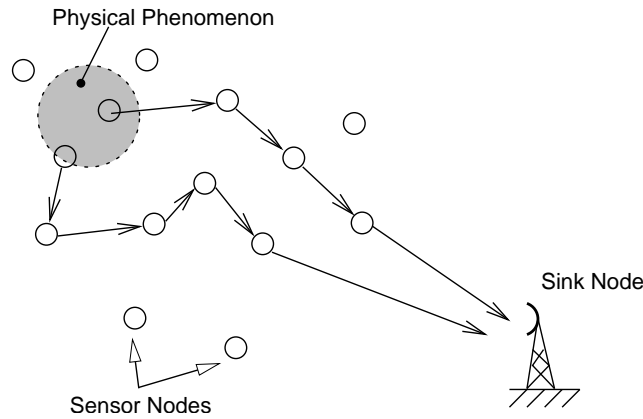


Fig. 4. Random topology.

We assume that the MAC protocol is the IEEE 802.11 standard. This serves to us as a baseline for comparison with 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^c. 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) $\gamma|_{dB} = -118\text{dBm}$ [9]. The calculation of the phenomenon range is not yet optimized and the phenomenon propagation is assumed to follow the propagation laws of the radio signals. In Fig. 5 and Fig. 6 are shown the transmission range of TwoRayGround and Shadowing models. In particular, the emitted power of the phenomenon is calculated according to a TwoRayGround propagation model [10]. The received

^cOther 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.

power at distance d is predicted by:

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L} \tag{1}$$

where G_t and G_r are the antenna gains of transmitter and receiver, h_t and h_r are the antenna heights for the transmitter and receiver, and L ($L \geq 1$) is the system loss.

The Shadowing model assumes that the received power at the sensor node is:

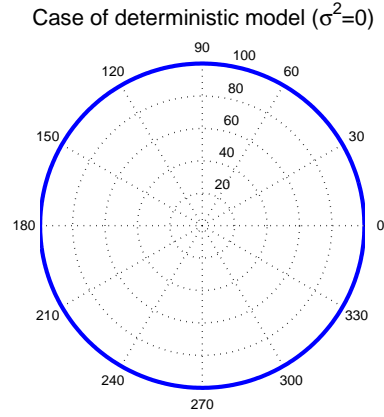


Fig. 5. Transmission range of TwoRayGround model.

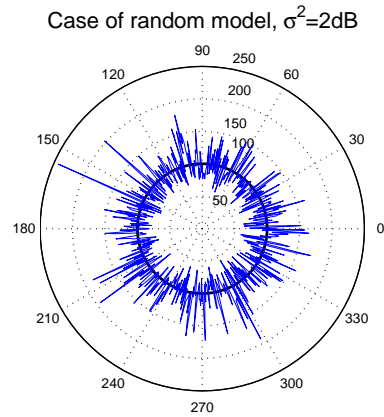


Fig. 6. Transmission range of Shadowing model.

$$P_r(d)|_{\text{dB}} = \underbrace{P_t|_{\text{dB}} - \beta_0 - 10\alpha \log\left(\frac{d}{d_0}\right)}_{\text{deterministic part}} + \underbrace{S_{\text{dB}}}_{\text{random part}} \tag{2}$$

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_{dB}^2 , that is $S_{\text{dB}} \sim \mathcal{N}(0, \sigma_{\text{dB}}^2)$. 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 the TwoRaysGround model. In Shadowing radio model, 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 depends also on the antenna height and the pathloss is:

$$\beta = 10 \log \left(\frac{(4\pi d)^4 L}{G_t G_r h_t h_r \lambda^2} \right) \quad (3)$$

where h_r and h_t are heights of the antenna for receiver and transmitter, respectively.

3 Goodput and Consumed Energy

The goodput is defined at the sink, and it is the received packet rate divided by the sent packets rate. Thus:

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

where $N_r(\tau)$ is the number of received packet at the sink, and $N_s(\tau)$ 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. As long as the WSNs is being used, a certain amount of energy will be consumed. The energy consumption rate directly affects the life-time of the network, i.e. the time after which the WSNs is unusable. The energy depletion is a function of the reporting rate as well as the density of the sensor network. Recall that the density of the network in the event-driven scenario correlates with the number of nodes that report their data. Accordingly, we define the consumed energy by the network in the detection interval τ as:

$$\bar{\Delta}(\tau) = \frac{NE_I - \sum_{i=1}^N e_i(\tau)}{N\tau} \quad (5)$$

where N is the number of nodes, E_I is the total initial energy of the sensor nodes, and $e_i(t)$ is the node energy at time t .

4 Simulation Results

We present the simulation results of our proposed simulation system for WSNs. We simulated the network by means of ns-2 simulator, with the support of NRL libraries^d. In this work, we simulated two pattern simulations considering mobile event and mobile sink. For AODV routing protocol, the sample averages of Eqs. (4) and (5) are computed over 20 simulation runs, and they are plotted from Fig. 7 to Fig. 14. In Fig. 7 and Fig. 8, we can clearly distinguish three operating zones. For low values of T_r , the network is uncongested. At a particular value of T_r (~ 10 pps), the Goodput decreases abruptly, because the network has reached the maximum capacity. For $T_r > 10$ pps, the contention and congestion periods

^dSince the number of scheduler events within a simulated WSNs can be very high, we applied a patch against the scheduler module of ns-2 in order to speed up the simulation time [11].

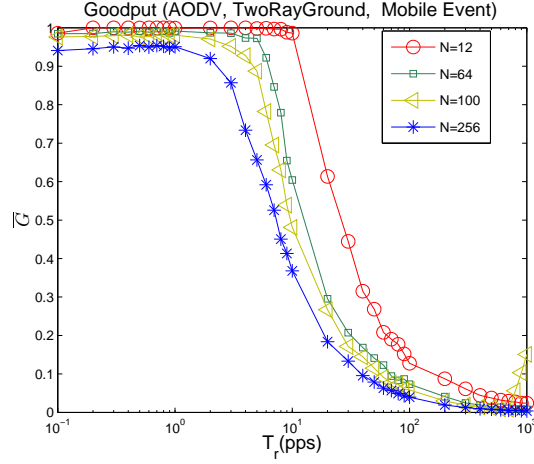


Fig. 7. Goodput for mobile event and TwoRayGround.

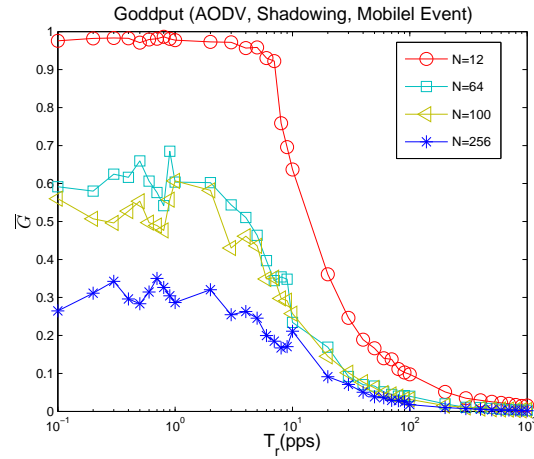


Fig. 8. Goodput for mobile event and Shadowing.

augment, thus increasing T_r does not ameliorate the Goodput, which has low values. In case of both TwoRayGround and Shadowing the goodput decreased with number of nodes increasing, as shown in Fig. 7 and in Fig. 8, respectively. However, we found that the Goodput of TwoRayGround is better than Shadowing. The explanation of this effect is not simple, because it is intermingled with the dynamics of MAC and routing protocols. However, intuitively we can say that in the case of Shadowing the on-demand routing protocols are affected by the presence of shadowing-induced unidirectional links. It is worth noting that AODV cannot use unidirectional links. Thus, the routing protocol spends most of the time in the searching of a bi-directional path. Thus, given a fixed detection interval, N_r can be much lower than its value in the case of the TwoRayGround model, where the discovered paths

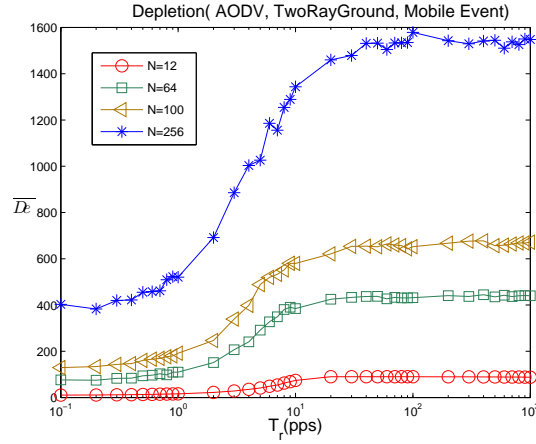


Fig. 9. Depletion for mobile event and TwoRayGround.

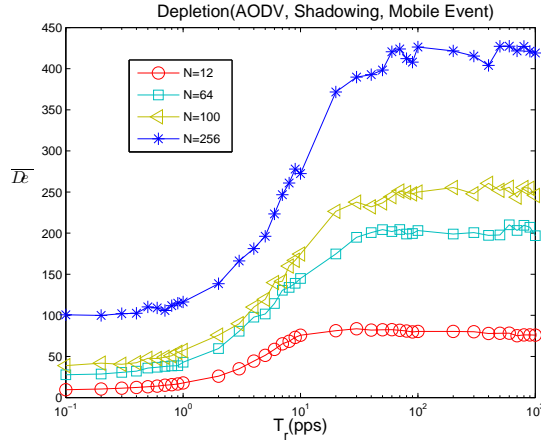


Fig. 10. Depletion for mobile event and Shadowing.

do not change over time^e. This fact may not affect the performance of the WSNs, because it depends on the requirements of the application. For high values of N , the augmented interference level and the path instability seem to be predominant [12, 13].

The consumed energy of Shadowing is about half of the TwoRayGround model as shown in Fig. 9 and Fig. 10. This is because the transmission range of Shadowing is irregular as shown in Fig. 6, but the transmission range of TwoRayGround is the same value in all directions as shown in Fig. 5. Therefore, the nodes which use the Shadowing radio model can transmit the packet farther than nodes that use the TwoRayGround radio model for the same transmission power.

Comparing Fig. 11 and Fig. 12, we found that the Goodput in case of mobile sink is better than in case of stationary sink when the transmission rate is lower 10pps. From Fig. 13 and Fig. 14, we see that the consumed energy in case of mobile sink is better than in

^eThis is true if we do not count the reliability of nodes, i.e. the probability of failure of sensor nodes.

case of stationary sink. This is because when the mobile sink is moving the average distance between sensor node and sink node becomes small and the number of relay nodes are reduced. Thus, the consumed energy is reduced.

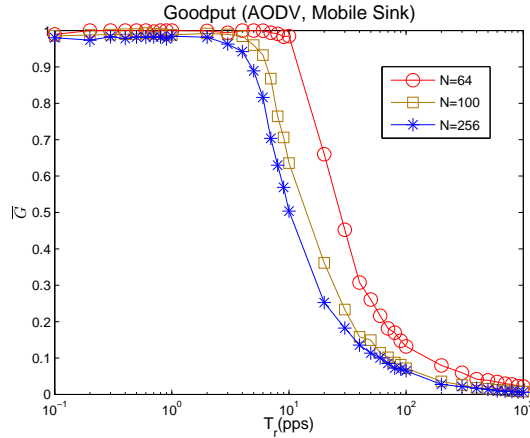


Fig. 11. Goodput for mobile sink and TwoRayGround.

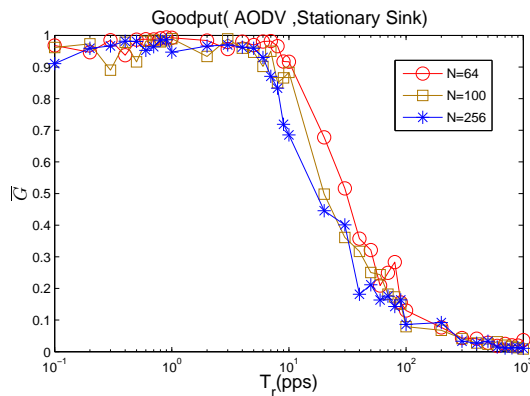


Fig. 12. Goodput for stationary sink and TwoRayGround.

5 Conclusions

In this paper, we presented the performance evaluation of WSNs for the case of mobile event and mobile sink. We carried out simulations considering TwoRayGround and Shadowing radio models, regular topology and AODV protocol. From the simulation results, we conclude as follows.

- The goodput of TwoRayGround is better than Shadowing. The goodput of TwoRayGround does not change too much when the number of nodes is increased. However, the goodput of Shadowing is decreased much more with the increase of number of nodes.
- The depletion of Shadowing is better than TwoRayGround in case of mobile event.

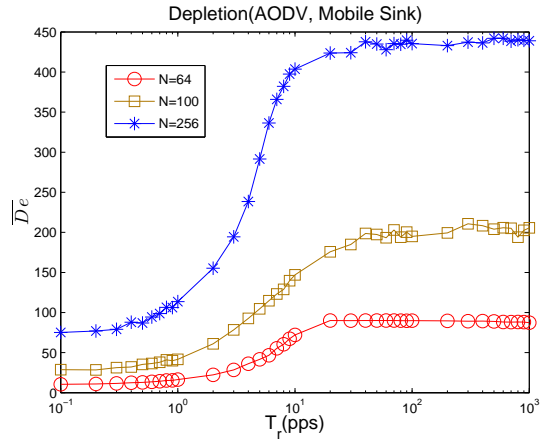


Fig. 13. Depletion for mobile sink and TwoRayGround.

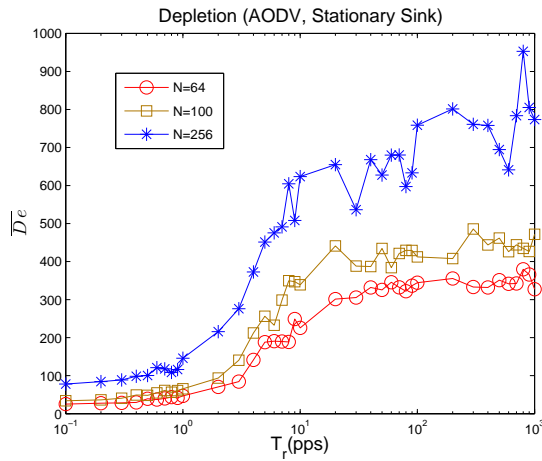


Fig. 14. Depletion for stationary sink and TwoRayGround.

- The goodput in case of mobile sink is better than stationary sink when the transmission rate is lower 10pps. For TwoRayGround, the depletion in case of mobile sink is better than stationary sink when the number of nodes is increased.

In the future, we would like to carry out more extensive simulations for mobile sensor nodes and multi-mobile sinks. We also would like to carry out simulations for wireless sensor and actor networks.

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