Chapter 17
Sink Mobility in Wireless Sensor Networks: From Theory to Practice

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ABSTRACT

The use of sink mobility in wireless sensor networks (WSN) is commonly recognized as one of the most effective means of load balancing, ultimately leading to fewer failed nodes and longer network lifetime. The aim of this chapter is to provide a comprehensive overview and evaluation of various WSN deployment strategies involving sink mobility as discussed in the literature to date. The evaluation of the surveyed techniques is based not only on the traditional performance metrics (energy consumption, network lifetime, packet delay); but, more importantly, on their practical feasibility in real-world WSN applications. The chapter also includes sample results of a detailed OPNET-based simulation study. The results outline a few key challenges associated with the use of mobile sinks in ZigBee sensor networks. By combining analytical and real-world perspective on a wide range of issues concerning sink mobility, the content of this book chapter is intended for both theoreticians and practitioners working in the field of wireless sensor networks.

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INTRODUCTION

The conventional wireless sensor network (WSN) architecture, as described in the majority of the literature, assumes the existence of a large number of miniature battery-powered sensor devices scattered over an area of interest and organized in an ad-hoc communication manner. The primary goal of the wireless sensors is to gather relevant data from the environment and, subsequently, to route the gathered data to a central processing node, commonly referred to as sink. The sink is generally assumed to have far superior capabilities than the ‘ordinary’ sensors, i.e.
nodes, and it serves as a gateway point to the end user of the system. In the networking literature, this type of systems comprised of multiple sending and one superior receiving station are known as \textit{many-to-one} systems.

From the communication perspective, the conventional many-to-one WSNs rely on multi-hop forwarding, i.e. routing, to deliver data to the sink. (In a WSN employing multi-hop routing, data is passed from the source node to the sink by being relayed by intermediate sensors, as illustrated in Figure 1.) Two most commonly recognized benefits of multi-hop routing are simplicity and energy efficiency (Wang, Hossam, & Xu, 2006). Namely, the physical-layer setup of a multi-hop WSN is pretty straightforward, as all nodes employ the same fixed radio range, regardless of their location and/or distance from the sink. In addition to being fixed, the nodes’ radio range is also assumed to be relatively short, i.e. needs to ensure communication between immediate topological neighbours only, and as such has a conserving effect on the nodes’ energy supplies. (Energy conservation is often considered to be the most important parameter in the design and operation of WSNs.)

In addition to the above advantages, there are also some serious challenges associated with the use of multi-hop routing in the conventional wireless sensor systems of many-to-one type, including:

1. \textbf{Funnelling Effect:} In many-to-one multi-hop WSNs, the nodes in the sink’s one-hop vicinity are required to ‘funnel’ (forward) data on behalf of all other, more distant, nodes (see Figure 1). Clearly, if such a network is to support a traffic-intense application with intervals of time in which the data collection rate dominates the data forwarding rate, e.g. video-based target tracking, congestion may start to build up at the bottleneck nodes of the sink’s one-hop neighbourhood. Consequently, the incidents of packet dropping and/or retransmission become more frequent, leading to increasingly degraded network performance.

2. \textbf{Hot-Spot Problem:} By being required to forward a disproportionately higher volume of traffic compared to other nodes in the network, the sink’s one-hop neighbours - also known as the ‘hot-spot’ nodes - tend to exhaust their energy and ‘die’ earlier relative to other nodes. Unless adequately dealt with, through measures that reduce the load and prevent the failure of the sink’s one hop neighbours, the hot-spot problem can lead to a complete isolation of the sink node, resulting in the failure of the entire network.

Based on the above, it should be clear that the funnelling effect and hot-spot problem are fundamentally related to each other – both appear as side-effects of multi-hop routing in WSNs of many-to-one type, and the former phenomenon can aggravate the later. Nevertheless, there are several key differences between the two phenomena:

a. The hot-spot phenomenon refers to the possibility of a topological collapse (complete sink isolation) due to a highly skewed distribution of routing load among the network.