Chapter 2
Received Signal Strength Models for Narrowband Radios

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ABSTRACT

The advancements in wireless communication technologies have enabled new sensing possibilities where the channel measurements of the radio are used for inferring physical changes in the surrounding environment. Relating the channel measurements to the location and actions of people has been of particular interest due to the wide range of application opportunities enabled by such a sensing capability. As an example, the low-amplitude received signal measurements of low-cost wireless communication systems have been used to detect the presence of a person, to locate and track them, identify gestures and activities of the person, and even monitor their vital signs. This chapter aims to give a deep insight on how people influence radio signals, how these effects are observed at the receiver antenna, and how the measurement system impacts the recorded measurements. These topics are presented to shed light on the relation between the location of people and signal strength measurements of narrowband radios.

INTRODUCTION

Recent advancements in different technologies have triggered a trend in replacing wired communications with wireless technologies, making them ubiquitously available in our everyday environment. Wherever we are, we inevitably interact with electromagnetic (EM) energy emitted by these systems, and alter the characteristics of the EM wave impinging on the receiver antenna. In particular, we alter received signal of the short-range systems, which indicate our presence and actions in close neighborhood of a link-line[1]. This variation has recently been used for non-invasive sensing by associating the

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received signal variations of different links to the same person in an environment, commonly referred to as *environmental sensing technology*.

The impact of a person on EM waveforms can be related to the person's location and actions even though they do not cooperate with the system by carrying a tag. This property makes the environmental sensing technology an attractive (indoor) device-free localization (Youssef, Mah, & Agrawala, 2007) option for conventional application areas such as ambient assisted living (Bocca, Kaltiokallio, & Patwari, 2013), residential monitoring (Kaltiokallio, Bocca, & Patwari, 2012), security and emergency surveillance (Bjorkbom, et al., 2013), roadside surveillance (Anderson, Martin, Walker, & Thomas, 2014), and forest monitoring (Alippi, Bocca, Boracchi, Patwari, & Roveri, 2015). It has also been shown that the technology can successfully estimate breathing rate of a person (Kaltiokallio O., Yiğitler, Jäntti, & Patwari, 2014), detect the presence of people in an environment (Kosba, Saeed, & Youssef, 2012), (Mrazovac, Todorović, Bjelica, & Kukolj, 2013), or identify when a person falls (Mager, Patwari, & Bocca, 2013). These application areas, however, are constrained by physical factors such as available information, and practical factors such as network management complexity, energy requirements, computational resource requirements and costs. The practical problems are solved by using state-of-the-art methods for existing network deployments since the technology relies on available link-quality measurements of wireless technologies to infer person's location and actions. On the other hand, the information contained in the measurements on the phenomenon of interest has a complex relation with the geometry and electrical properties of the objects[2] in the environment, which is referred to as *communication channel*. As the quality (resolution in terms of both bandwidth and amplitude) of the channel measurements increases, the information about a person increases and the phenomenon of interest can be better inferred. However, higher quality channel measurements also imply a more complex and expensive systems. In this regard, received signal strength (RSS) measurements is very attractive option since it is ubiquitously available also on low-cost devices. In this chapter, the RSS measurements of narrowband wireless communication systems are elaborated in depth, and the variation of the measurements with the person's location and movement are investigated.

The RSS is the received signal power calculated over a certain time duration, and it depends on the propagation channel, interference sources in the environment, transmission power and constant gains of the radio hardware. The information carried by such a compact measure can be used for link quality assessment (Baccour, et al., 2012), adaptive transmission power control (Lin, et al., 2006), and node localization (Patwari, et al., 2005). When the interference sources can be ignored and the radio gains are constant, the RSS varies solely due to propagation channel variations, which also enables RSS-based environmental sensing systems. These systems effectively compare the RSS measurements with the stationary channel case, i.e., base-line RSS, and typically process low-amplitude signals in order to infer the phenomena of interest. Therefore, the validity and accuracy of the RSS models that relate the phenomena of interest with the measurements are very important for successful environmental sensing applications.

This book chapter begins with example real-world RSS measurements to demonstrate how a person affects the RSS and how the related works have modeled these changes. Thereafter, the considered RSS measurement system is introduced, and a general measurement model is presented. The underlying physics of interaction of objects with propagating EM energy is reviewed before, we characterize the temporal variations of the RSS. For this purpose, we elaborate an idealistic deployment scenario, which enables drawing the relation between interacting object's position to the observed RSS variations. Based on these observations, a four-state temporal RSS model is introduced after deriving that the RSS measurements approximately have log-normal distribution under static channel conditions. The

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