A Review Paper on Radio Tomographic Imaging

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Abstract: **Radio Tomographic Imaging (RTI) is an growing technology for imaging passive objects (objects that do not carry a transmitting device) with wireless networks. This paper presents a linear model for using received signal strength (RSS) measurements to obtain images of moving objects. A Gaussian noise model is assumed, the precision of which is examined through a measurement campaign. A maximum a posteriori (MAP) estimator is derived as an image reconstruction algorithm, and an experimental implementation of RTI is presented with resultant images.**

INTRODUCTION

Radio tomographic imaging (RTI) is an growthing application which offers a new way to image passive objects in buildings and outdoor environments using received signal strength (RSS). The reduction in costs for radio frequency integrated circuits (RFICs) and advances in peer-to-peer data networking, have made realistic the use of hundreds or thousands of simple radio devices in a single RTI deployment. We describe in this paper an imaging system which has power that rises as Metcalf's Law with the number of nodes, and suggest using low-complexity devices to enable large numbers of nodes. Radio tomography takes the advantages of two well-known and widely used types of imaging systems. First, radar systems transmit RF probes and receive echoes which caused by the objects in an environment. A delay between transmission and reception indicates a distance to a scatterer. Phased array radars also compute an angle of bearing. Such systems image an object in space based on

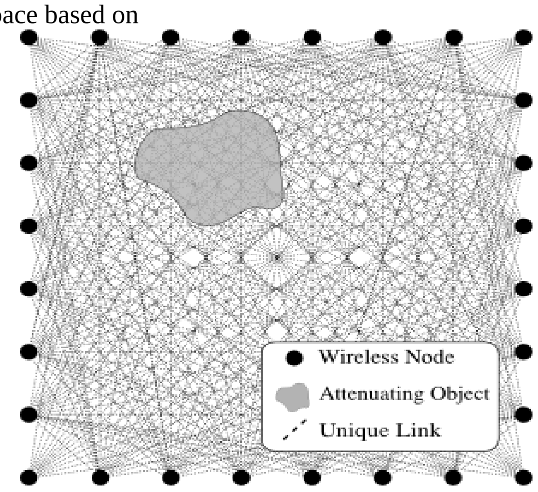

Fig. 1. An illustration of an RTI network. Each node broadcasts to the others, making many projections that can be used to reconstruct an image of objects inside the network area.

Reflection and scattering. Secondly, computed tomography (CT) methods in medical and geophysical imaging systems send signals along many different paths through a medium and measure the magnitude and phase of the transmitted signal. The measurements on many paths is used to count an estimate of the spatial field of the transmission parameters throughout the medium. Radio tomography is also a transmission-based imaging method which measures received signals on many different paths from a medium, however, it does so at radio frequencies similar to radar systems. Tomography at radio frequencies across large, disarrange environments experiences two major additional complications compared to typical CT systems. • RTI systems measure only signal magnitude. Medical tomographic systems have motorized sensors which are used to measure phase differences at different positions. The high expense and deployment complexity involved Fig. 1. An illustration of an RTI network. Each node broadcasts to the others, creating many projections that can be used to reconstruct an image of objects within the network area. in providing such a capability makes it inconsistent with the low-cost application space we target with RTI. • The use of RF as opposed to much higher frequency EM waves (e.g., x-rays), introduces valuable non-line-of sight (NLOS) propagation in the transmission measurements. Signals in standard mercantile wireless bands do not travel in just the line-of-sight (LOS) path, and instead propagate in many directions from a transmitter to a receiver. Irregardless the difficulties of using RF, there is a major advantage: RF signals can travel through obstructions such as walls, trees, and smoke, while optical or infrared imaging systems cannot. RF imaging will also work in the dark, where video cameras will fail. Even for applications where video cameras could work, privacy concerns may prevent their deployment. An RTI system provides current images of the location of people and their movements, but cannot be used to recognise a person.

APPLICATIONS

One main application of RTI is to decrease injury for correctional and law enforcement officers; many are injured each year because they lack the ability to detect and track offenders through building walls. By showing the locations of people and walls within a building during hostage situations, during building fires, or after an earthquake, RTI can help law enforcement and emergency responders to know where they should focus their attention and realization efforts. Another application is in automatic monitoring and control in 'smart' homes and buildings. Some building monitoring systems detect motion in a room and use it to control lighting, heating, air conditioning, and even noise cancellation. RTI systems can further determine how many people are in a room and where they are placed, providing more precise control. Generally RTI has application in security, protection and monitoring systems for indoor and outdoor areas. For example, existing security systems are trip-wire based or camera-based. Tripwire systems find out when a person crosses a boundary, but do not track the person when they are within the area. Cameras are ineffective in the dark. An RTI system could operate both as a trip-wire, alerting when intruders enter into an area, and tracking where are at all times while they are inside, regardless of availability of lighting or obstructions.

OVERVIEW

This paper analyse in detail the use of RF path losses on links between many pairs of nodes in a wireless network in order to image the changes in attenuation that occur within the area of their deployment. We refer to this problem as radio tomographic imaging (RTI). In general, when an object moves into the area of dilation, we expect that links which pass through that object will, on average, experience higher shadowing losses. We explore the inverse perspective, that is, the use of the measurement of additional path losses on multiple, intersecting links to image the attenuation within the area and infer the location of an attenuating object. Section II presents a linear model describing RSS measurements to the moving attenuation occuring in a network area, and investigates statistics for noise in dynamic multipath environments. Section III derives the MAP solution for obtaining an attenuation image using Gaussian prior assumptions. Section IV represent the setup of an actual RTI experiment, the parameters used, and the resultant images.

RELATED WORK

RF-based imaging has been dominated in the commercial realm by ultra-wideband (UWB) based through-the-wall (TTW) imaging devices, including include Time Domain's Radar Vision , Cambridge Consultants' Prism 200 and Camero Tech's Xaver800. Each device is a phased array of radars which transmit UWB pulses and then record the return echoes and calculate a range and bearing. These devices are accurate close to the device, but inherently suffer from precision and noise issues at long range due to monostatic radar losses and large bandwidths, and involve only one device. Some initial attempts allow 2-4 of these high-complexity devices to collaborate to improve coverage. In comparison, in this paper we discuss using dozens to hundreds of low-strength collaborating nodes, which measure transmission rather than scattering and reflection. Further, UWB uses extremely wide RF bandwidth, which will border its application to commercial, non-emergency applications. Our paper investigates using radios with relatively small bandwidths. To emphasize the small expected bandwidth compared to UWB, some relevant research is being called " ultra narrow band" (UNB) radar . These systems propose using narrow band transmitters and receivers expand around an area to image the environment within that area. Measurements are phase-synchronous at the multiple sensors around the area. Such techniques have been used to detect and locate objects buried under ground using what are effectively a synthetic aperture array of ground-penetrating radars. Experiments have been reported which measure a static environment while moving one transmitter or one receiver, and measure a static object on a rotating table in an anechoic chamber in order to simulate an array of transmitters and receivers at several different angles . Because in this paper we use low complexity, non-coherent sensors, we can expand many sensors and image in real time, enabling the study of tracking moving objects. We present experimental results with many devices in real-world, cluttered environments.

CONCLUSION

Radio Tomographic Imaging (RTI) is a method of imaging passive objects within a wireless network. This paper presented a linear model relating signal strength (RSS) measurements to attenuation occuring within spatial voxels of a network area. A measurement campaign was performed to accredit a Gaussian assumption for the noise vector statistics. These measurements were taken indoors when people were moving near the links, capturing the effects of fading. Resultant quantile-quantile plots indicate that a Gaussian noise assumption is reasonable, but future work will entail the use of more complex noise models. RTI is an ill-posed inverse problem, and regularization must be incorporated to obtain usable results. In this study, the image is supposed to be Gaussian, and a MAP estimator is used for image reconstruction. The MAP estimator provides a simple and closed-form solution which is mathematically simple and suitable for real-time implementation. Other forms of inverse problem regularization, previous assumptions, and image reconstruction algorithms topics for future research. An implementation of an RTI system using 28 nodes operating at 2.4 GHz. Results show that the system is effective in creating attenuation images of humans standing in areas on the order of hundreds of square feet.Finally, images created via RTI provide a natural framework to track targets that move inside a wireless network.

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