M2M Distance Estimation in Indoor Wireless Network

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Abstract—Distance estimation identifies the distance between two machines (M2M: Machine to Machine) in wireless network. Such estimates are an important component of localization systems, because they are used by the position computation and localization algorithm components. Different methods, such as received signal strength indication (RSSI), time of arrival (ToA), and time difference of arrival (TDoA), can be used to estimate a M2M distance. Nowadays, a lot of systems have tried to estimate M2M distance using different models in wireless networks. For example, the Active Badge System used an infrared signal. Cricket, developed at MIT, uses TDoA method. Global Positioning System (GPS) uses ToA. RADAR, developed at Microsoft, uses RSSI to estimate M2M distance. It is primarily based on an 802.11 Wireless LAN. SpotON is a RSSI based ad-hoc localization system. We describe and analyze some of the major approaches and systems for M2M distance estimation in indoor wireless network.

Keyword—Machine to Machine, Distance estimation, received signal strength indication, time of arrival, time difference of arrival, wireless network.

I. INTRODUCTION

Wireless Sensor networks (WSNs) are one of the essential research domains. There are many applications for WSNs in military and civil applications [1]. The M2M distance estimation is a fundamental issue for lots of applications of indoor WSNs, such as a Bluetooth and zigbee. Distance estimation identifies the distance between two machines (M2M: Machine to Machine) in wireless network.

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II. M2M DISTANCE ESTIMATION METHODS

A. RSSI

RSSI can be used to estimate the M2M distance based on the received signal strength from another machine. The longer the distance to the receiver machine, the lesser the signal strength at received machine. Theoretically, the signal strength is inversely proportional to squared distance, and there is a known radio propagation model that is used to convert the signal strength into distance. However, in real environments, it is hard to measure distance using RSSI because of noises, obstacles, and the type of antenna. In these cases it is common to make a system calibration [7], where values of RSSI and distances are evaluated ahead of time in a controlled environment. The advantage of this method is its low cost, because most receivers can estimate the received signal strength. The disadvantage is that it is affected by noise and interference. So, distance estimation may have inaccuracies. Some experiments [8] show errors from 2 to 3 m in some scenarios. Distance estimation using RSSI in real-world
applications is still questionable because of inaccuracy [9]. However, RSSI could become the most used technology of distance estimation from the cost/precision viewpoint because of low cost [10]. A. Awad et al. [1] presented intensively discuss and analyze approaches relying on the received signal strength indicator. The most important factor for proper distance estimation is to choose a transmission power according to the relevant distances. It showed that even for noisy indoor environments an average positioning error of 50cm on an area of 3.5 x 4.5 m is possible by choosing the RF and algorithm parameters carefully based on empirical studies.

S. Feldmann et al. [11] also presented an indoor positioning system based on signal strength measurements, which were approximated by the received RSSI in a mobile device. The functional dependence between the received RSSI and the distance was got by a well fitted polynomial approximation, as shown in Figure 1.

B. ToA

In ToA, the M2M distance is directly proportional to the time the signal takes to propagate from one machine to another, as shown in Figure 2 [12]. ToA needs precisely synchronized machines.

The distance between two machines is proportional to the signal transmitted time. That is, if a transmitter sends a signal at time \( \text{time}_1 \) and a receiver receives the signal at time \( \text{time}_2 \), the distance between transmitter and receiver is \( d = P_r \times (\text{time}_2 - \text{time}_1) \), where \( P_r \) is the propagation speed of the radio signal, and \( \text{time}_1 \) and \( \text{time}_2 \) are the times when the signal was transmitted and received. S. Schwarz et al. [13] presented a concept to measure the distance between two IEEE 802.15.4 compliant devices using ToA. It shows that compared to signal correlation in time, the phase processing technique yields an accuracy improvement of roughly an order of magnitude.

C. TDoA

TDoA is based on the difference in the times at which multiple signals from a single machine arrive at another machine. The machines must have extra hardware for sending two types of signals simultaneously, as shown in Figure 3. These signals must have different propagation speeds, like RF and ultrasound. N. Priyanta et al. [14] presented a TDoA method using different propagation speed signals, like radio/ultrasound. K. Whitehouse et al. [7] used radio/acoustic signals. Usually, the first signal propagation speed is light, while the second signal has slower propagation speed. The second signal is six orders of magnitude slower than the first signal.

An example of TDoA suitable for WSNs is used by [8] and depicted in Figure 3, where the ultrasound pulse and radio signal are sent simultaneously. A receiver machine computes the difference time of the two signals. The distance can now be computed by the formula \( d = (P_r - P_u) \times (\text{time}_2 - \text{time}_1) \), where \( P_r \) and \( P_u \) are the propagation speeds of the radio and ultrasound respectively.
where \( P_r \) and \( P_s \) are the propagation speed of the radio signal and ultrasound pulse, and \( \text{time}_1 \) and \( \text{time}_2 \) are the received times of the radio signal and ultrasound pulse, respectively. Another different and interesting way of computing distance among machines using the TDoA is proposed by Fu et al. [15], and is based on the direct sequence spread spectrum (DSSS) modulation technique. The distance estimation errors using TDoA are several centimetres. Experiments error with ultrasound performed in [8] is about 3 cm where M2M distance was 3 m. In [16], the experiments error with acoustic sound is about 23 cm where M2M distance was 2 m. TDoA system has precise distance estimation accuracy. However, it also has disadvantages. It needs extra hardware to send the second signal, which increases cost. And it has limited range of the second signal, which is about between 3 and 10 m according as transmitter power. To save a cost, Y. FUKUJU et al. [17] presented a TDoA system that reduces configuration cost.

III. Location System Using M2M Distance Estimation

The Active Badge System finds location information using an infrared signal [2]. Each person wears a small infrared badge. The badge sends a unique packet periodically or on demand. A server receives badge data using fixed infrared sensors in building and gathers this data. The Active Badge system provides absolute location information using this infrared distance information. Infrared signal has an effective range of several meters because of diffusion. Therefore, infrared signal range is limited to small or medium rooms. As mentioned above, drawbacks are limited range of infrared sensors and usage of diffused infrared in fluorescent lighting or direct sunlight.

Cricket uses TDoA method [3]. M2M distance error is about 3 cm, but this causes a huge burden on the receiver machine due to distributed computation and processing of ultrasound pulses and RF signal. The Cricket Location Support System finds location information using ultrasound pulse and RF signal. The RF signal is used for synchronization of the time measurement. Cricket estimates distance using TDoA and then finds location information using distance information, however Cricket does not require a grid of ceiling sensors with fixed locations because its mobile receivers perform the timing and computation functions. A receiver receives multiple beacons, so it triangulates its position. Cricket has advantages that it has privacy and decentralized scalability. It also has disadvantages that it does not have centralized management and more it has the computational and power burden for timing and processing both the ultrasound pulses and RF signal on the mobile receivers.

RADAR was developed at Microsoft and used RSSI to estimate M2M distance [5]. It is based on an 802.11 Wireless LAN. A building-wide tracking system based on the IEEE 802.11 LAN wireless networking technology. RADAR measures the signal strength and signal-to-noise ratio at the base station, and then it computes the position within a building using these data. RADAR’s scene-analysis implementation has position error within about 3 meters with 50 percent probability, while the signal strength lateration implementation has position error about 4.3-meter with 50 percent probability.

SpotON is a RSSI based ad-hoc localization system [6]. The SpotON system implements ad-hoc lateration with low cost tags. SpotON tags estimate distance between tags using radio signal attenuation. It can be used for relative and absolute position determination. In an ad-hoc location system, all of the machines become mobile machines with the same sensors and capabilities. To estimate their locations, machines cooperate with other nearby machines by sharing RSSI data. Machines in the cluster are located relative to one another or absolutely if some machines in the cluster have known locations. The techniques for building ad-hoc systems include triangulation, scene analysis, or proximity. Location sensing with ad-hoc infrastructure has a high scalability.

IV. Conclusions

This paper addresses the distance estimation method and system in wireless network. RSSI could become the most used technology of distance estimation from the cost/precision viewpoint because of low cost. However, some experiments show distance errors about several meters in some scenarios. Therefore, if precise distance estimation is needed, TDoA should be used for distance estimation. The distance estimation errors using TDoA are several centimetres. Experiments error with ultrasound performed is about 3 cm where M2M distance was 3 m. However, it is expensive method because it needs extra hardware for sending two types of signals simultaneously. So, location systems used appropriate distance estimation method. For example, Cricket uses TDoA method, GPS system used TDoA method, and RADAR used RSSI distance estimation method.

REFERENCES


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