Efficient Indoor Location-Based System using Sensor Networks

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Summary
In indoor location-based systems, there are many important design considerations including scalability, privacy, and performance of localization. Among these considerations, accuracy is the most important factor that dominates the performance of localization. The accuracy of a location-based system is determined by receiving information from multiple beacon nodes. However, the increment of the number of deployed beacon nodes results in a lot of collisions and much interference among signals, and it can degrade the performance of the location-based system. In this paper, we propose a localization scheme based on both the law of cosines and on-demand beacon management mechanism. In our localization scheme, based on the law of cosines, only two beacon nodes are deployed to estimate the location. The on-demand beacon management mechanism has been proposed in this paper to minimize collisions and interference. This mechanism can also increase the probability of transmission from the nearest beacon and reduce error probability. Our simulation results show that the proposed scheme improves accuracy even though it uses a small number of sensor nodes and achieve a lower error rate than that of the traditional location-based system.

Key words:
Sensor networks, Indoor location-based system, Localization scheme, TDoA, Beacon management mechanism

1. Introduction

Various applications that have network functions require human and object tracking in the upcoming era of ubiquitous computing. Recently, the most popular method for localization has been GPS (The Global Positioning System) [1]. GPS provides global coverage but requires specialized equipment. Furthermore, GPS is not capable of operating indoors because of the large attenuation introduced by the walls and ceilings of buildings; therefore, it cannot achieve a ubiquitous localization method.

There are many studies on location-aware applications for home network systems. For these applications, a sensor network localization system has been researched, and Cricket system [2] that is developed by MIT has achieved high accuracy. To expand localization space, many sensor nodes are deployed, creating lots of interference and collisions. These interferences and collisions can degrade the performance of the whole localization system.

In indoor location-based systems, there are many important design considerations such as scalability, privacy, and performance of localization. Among these considerations, accuracy is the most important factor that dominates the performance of localization. The accuracy of a location-based system is determined by receiving information from multiple beacon nodes. However, the increment of the number of deployed beacon nodes results in a lot of collisions and much interference among signals, and it can degrade the performance of the location-based system [3].

In this paper, we propose a localization scheme based on both the law of cosines and on-demand beacon management mechanism. In our localization scheme, based on the law of cosines, only two beacon nodes are deployed to estimate the location. Because localization is enabled to use a small number of nodes, it can reduce the collision probability and improve reliability. In order to minimize collisions and interference, the on-demand beacon management mechanism has been proposed in this paper. This mechanism can also increase the probability of transmission from the nearest beacon and reduce error probability. We implement the testbed of the proposed indoor location-based system using Cricket motes. Our testbed improves accuracy even though the testbed uses a small number of sensor nodes. We also evaluate the performances of the proposed localization and beacon management scheme by using the ns-2 network simulator. Our simulation results show that the proposed scheme achieves a lower error rate than that of the traditional location-based system.

The rest of this paper is organized as follows. In Section II, research works related to indoor location-based systems are discussed. Details of the proposed localization scheme are then presented in Section III. In Section IV, the implementation details of the proposed localization scheme are described. The simulation results are presented in Section V. Finally, Section VI presents the conclusion.

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2. Related Work

2.1 Localization Schemes

RSS (Radio Signal Strength) is one of the simplest approaches that have been used for estimating the distances between nodes. An example of this type of approach is the RADAR system [4], where the signal strength from static nodes is used to roughly track mobile indoor nodes. In this approach, the energy of a radio signal diminishes at the square of the distance from the signal's source. As a result, a node listening to a radio transmission should be able to use the strength of the received signal to calculate its distance from the transmitter. However, RSS measurements contain noise that occurs because radio propagation tends to be highly non-uniform in real environments. Even though RSS is too inaccurate for many applications, the radio can still be used to assist localization. The key observation is that if two nodes can communicate by radio, then their distance from each other is less than R with high probability, where R is the maximum range of their radios, no matter what their signal strength reading is. Thus, simple connectivity data can be useful for localization purposes [5].

The range between nodes can be estimated far more accurately by estimating the time difference between the transmission and reception of slow travelling signals such as ultrasound or acoustic waves. By transmitting both radio and ultrasound or acoustic waves at the same time, a receiver node has a transmission reference time stamp according to which the time difference is calculated. The obvious downside of this approach is the need for nodes to have additional hardware for dealing with acoustic signals [6].

Several research methods for range-free protocols emerged, which achieved localization in low rate wireless personal area networks. Because these range-free solutions only use COTS radio transceivers as the basis of localization, they do not require additional hardware. DV-HOP [7] is among the most well known range-free protocols. In DV-HOP, the readers broadcast their location over a network with a hop count. The nodes calculate their position according to the received reader locations, the hop count from the reader, and the average distance per hop. APIT [8] resolves the localization problem by partitioning the environment into triangular regions between anchor nodes. The Amorphous Positioning algorithm [9] performs estimation via a neighbor information exchange. However, the range-free protocols have poor accuracy in finding and tracking assets [10].

2.2 Indoor Location-based Systems

Active Badges [11] is an indoor sensing system that transmits a unique infrared signal every 10 seconds and a central server that collects signals through fixed sensors. The Active Badges system has several limitations when practically applied to location tracking. The main limitations are difficulty in locations with fluorescent light or sunlight, which generate infrared emissions and range over some meters and use multiple infrared beacons for larger areas.

The Cricket indoor location system [2] that is developed by MIT is indoor location system for pervasive and sensor-based computing environments. In this approach, the device carried by the person determines the location itself. This ensures the privacy of the person. Beacons attached to the ceiling periodically send a radio and ultrasonic signal. Using multiple signals from different beacons, the personal device calculates the current position. In further work, Cricket was extended to track moving objects. An outlier rejection component is used to eliminate the measurement failures by deleting extremal values. Another component is the least square solver that minimizes the squared mean failures. Current states are stored by an extended Kalman-filter that can even predict future states.

In the Cricket indoor location system, the transmission rate of the ultrasound signal is slower than that of the RF signal; interference among beacon signals are more serious when multiple beacon nodes are used. This interference phenomenon from the beacon signal occurs because the listener node does not correctly receive the RF signal and ultrasound signal of the beacon node. Fig. 1 shows the case that listener node does not correctly receive the beacon signal.

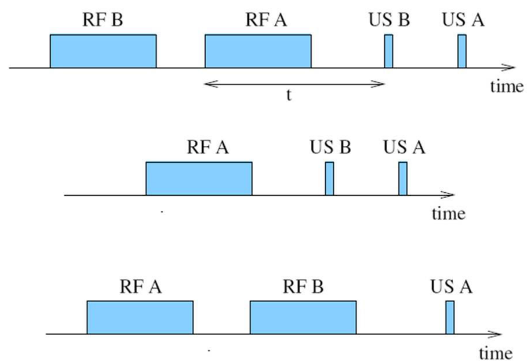

Fig. 1 Interference caused by beacon signal

In order to cover a wide indoor region, cricket requires more beacon nodes; as a result, interference among the beacon signals and collision probability is increased. In addition, the listener node not only receives the RF signals of the adjacent beacon node, but it also receives those far from the listener node. It causes collision induced by the hidden terminal problem. Fig. 2 shows the outlier probability as a different number of beacons [12].

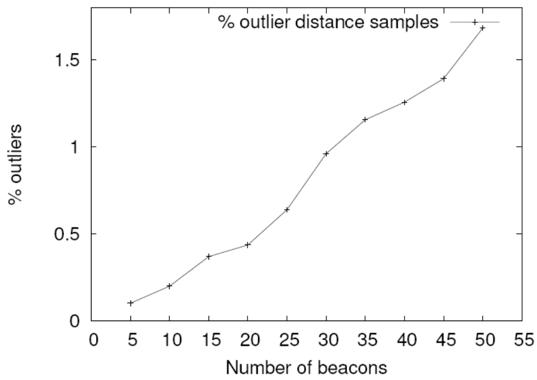

Fig. 2 Outlier probability as different number of beacons

3. Indoor Location-based Systems

We propose a new localization scheme based on both the law of cosines and on-demand beacon management mechanism. In our localization scheme, based on the law of cosines, only two beacon nodes are deployed to estimate location. The on-demand beacon management mechanism has been proposed in order to minimize collisions and interference. This mechanism can also increase the probability of transmission from the nearest beacon and reduce the error probability.

3.1 Localization Scheme

The proposed system is based on TDoA (Time Difference of Arrival). Because a TDoA-based protocol uses the time difference among readers to provide location information, the precise time measurement of radio signals and precise time synchronization among readers are essential. Fig. 3 shows the localization scheme based on TDoA using radio and ultrasonic signals.

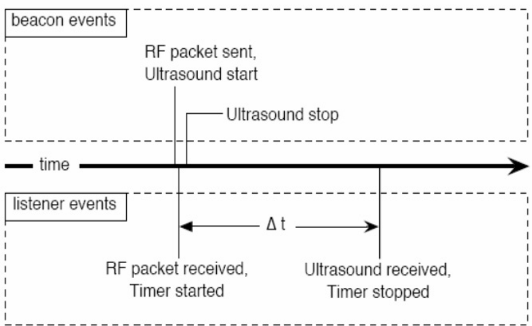

Fig. 3 TDoA based localization scheme

Our indoor location-based system architecture uses both RF and ultrasound signals [13]. The speed of ultrasound signals is the same as that of sound, about 340 m/s, which is significantly slower than the speed of light. Therefore, it is possible to estimate the distances among nodes by using the TDoA between RF and ultrasound [1].

In the proposed localization scheme, the listener node location is measured by TDoA using only the two beacon nodes. The listener node knows the distances among the listener node and beacon nodes that is the three sides of a triangle. Therefore, we can calculate the cosine value of any angle using the law of cosine. Equation (1) shows $cos\ \theta$ as shown in Fig. 4. Equation (2) shows the distance between (0,0) and x that is of the x-axis coordinates of the listener node.

$$cos\ \theta = \frac{d3^2 + d1^2 + d2^2}{2 \times d3 \times d1} \qquad (1)$$

$$x = cos\ \theta \times d1 \qquad (2)$$

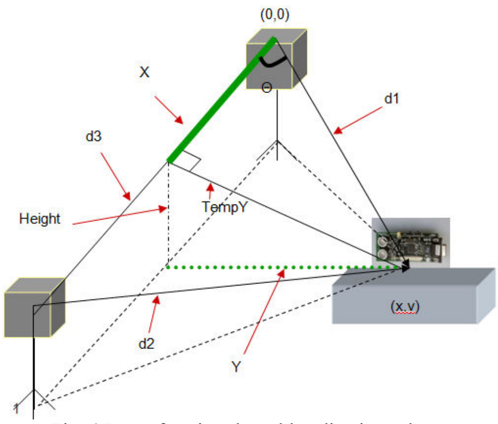

Fig. 4 Law of cosines based localization scheme

The Y-axis coordinates of the listener node are calculated by using the Pythagorean Theorem. TempY is one side of the right-angled triangle and consists of X, TempY, and d1. Y is also one side of the right-angled triangle and consists of Height, TempY, and Y. We can calculate the distance of Y by applying the two right-angled triangles to Pythagorean Theorem. Equation (3) shows the y-axis coordinates of the listener node.

$$y = \sqrt{d1^2 - X^2 - Height^2} \qquad (3)$$

3.2 Beacon Management Mechanism

We propose an on-demand beacon management mechanism to minimize communication problems, such as collision and interference. It can increase the probability of transmission chance from the nearest beacon and reduce the error probability that is affected by the characteristics of ultrasound. Fig. 5 shows the deployment of the beacon management mechanism that consists of multiple beacon nodes and one listener node.

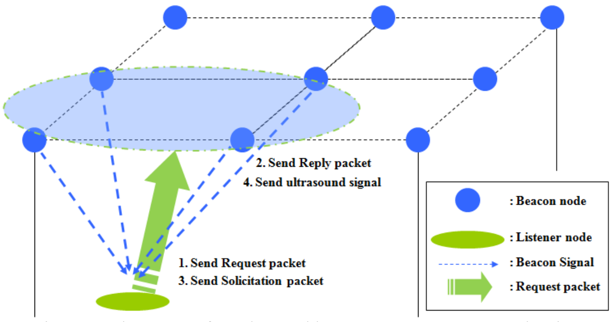

Fig. 5 Deployment of on-demand beacon management mechanism

The listener node periodically broadcasts the Request packet to the beacon nodes. Then, these beacon nodes respond the Reply packet if the received signals exceed the threshold of the signal strength. After the listener node runs the ordering algorithm, the node broadcasts the Solicitation packet according to a predetermined order of transmission. Interference with the RF signal occurs if the listener node receives different ultrasound signals at the same time. Therefore, the listener node selects a beacon node that transmits the beacon using Solicitation packet. A beacon node that receives the Solicitation packet checks the priority field. If the node finds its own ID, then it sends the TDoA packet to the listener node. If the listener node receives the TDoA Packet, then it transmits the Polling Token packet to the beacon node selected to be transmitted next. Then, the next priority node transmits the TDoA packet. This process is repeated until all beacon nodes included in the order list have completed transmission of the TDoA packets. Fig. 6 shows the process of the on-demand beacon management mechanism.

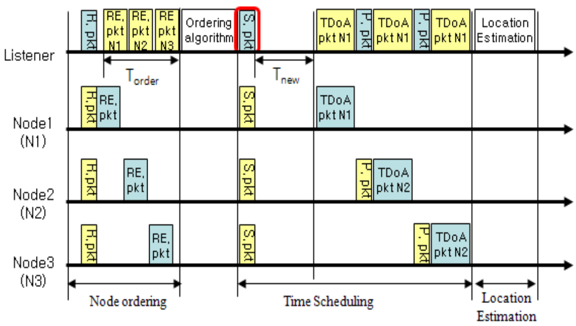

Fig. 6 Process of beacon management mechanism

To reduce the error probability of ultrasound signals, the listener node must receive the beacon from a distance as close as possible. Equation (4) shows the relation between RSSI of beacon node and the distance of signal from the transmitted packet. RSSI is in inverse proportion to the distance.

$$RSSI = P_t - PL(d_0) - 10\eta \log_{10} \frac{d}{d_0} + X\sigma \qquad (4)$$

The beacon node makes the decision of the listener node's state based on the calculated RSSI value. Fig. 7 shows the beacon node selection scheme using RSSI. If the received RSSI value is above the threshold, then the listener node transmits a Reply packet.

If (RSSI(Request Packet) ≧ Threshold)
: Send Reply Packet
Else (RSSI < Threshold)
: Listen Request Packet

Fig. 7 Beacon node selection using RSSI

Fig. 8 shows the definition of packet format using the proposed on-demand beacon management mechanism. All packets have the packet type field interpreted by beacon and listener nodes.

Symbol	Type	Byte1	Byte2	Byte3
R. pkt	Request Packet	Packet Type		
Re. pkt	Reply Packet	Packet Type	Node ID	
S. pkt	Solicitation Packet	Packet Type	Priority	
P. pkt	Polling Token Packet	Packet Type	Source ID	Dest. ID
TDoA pkt	Ultrasound Signal			

Fig. 8 Definition of packet format

4. Implementation

We implement the testbed of the indoor location-based system using Cricket motes [2] and a robotic vacuum cleaner. The Cricket motes communicate with each other via RF to determine their locations. Serial communication is used between the robotic vacuum cleaner and Cricket, or between the PC and Cricket. Fig. 9 shows our testbed of the indoor location-based system.

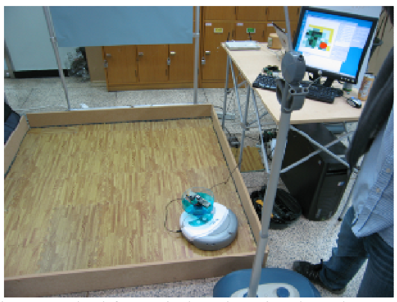
Fig. 9 Testbed for an indoor location-based system

The application program is developed to monitor the location of a robotic vacuum cleaner and cleaning status of the room, and it can directly send commands to the robotic vacuum cleaner. The application server transmits the listener node's location to its client. Also, it transmits the command from the client to the listener node. Fig. 10 shows the user interface of the application program in our indoor location-based system.

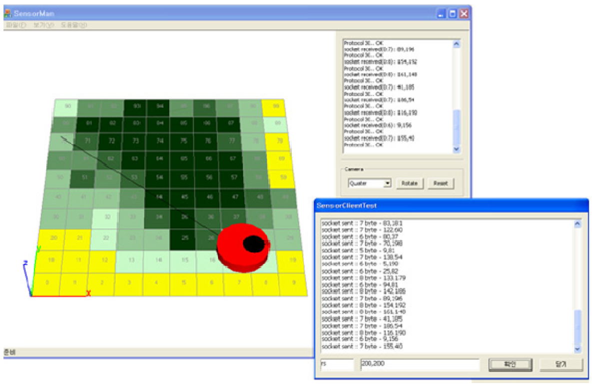

Fig. 10 User interface of the application program

5. Performance Evaluation

In order to evaluate the performances of the proposed localization and beacon management scheme, we use the ns-2 network simulator. The beacon nodes are deployed at intervals of two meters in simulation topology and transmit the beacon signal at one second intervals. Fig. 11 shows the deployment of beacon nodes in the simulation topology. We compare the proposed scheme with the Cricket system that is known to be the most accurate system for indoor location-based system with sensor networks. Because any other indoor location approaches do not address the problem of interference among the beacon signals, we do not compare proposed scheme with them.

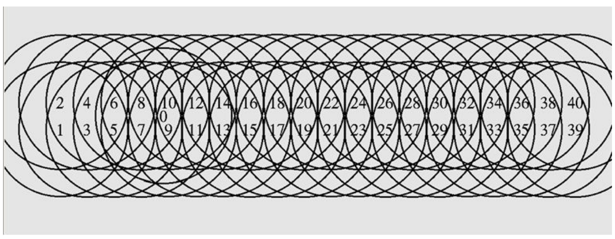

Fig. 11 Deployment of beacon nodes

Fig. 12 shows the number of the received beacons according to the number of beacon nodes. In Cricket, the number of received samples is increased as the number of beacon nodes increases up to 5 nodes; however, when the number of beacon nodes is over 5, the number of received samples is decreased. It is due to occurring interference among the beacon signals because all beacon nodes simultaneously transmit the RF signal and ultrasound signal. Otherwise, the proposed scheme can increase the probability of transmission chance from the nearest beacon and reduce the error probability that is affected by the characteristics of ultrasound through on-demand based beacon management.

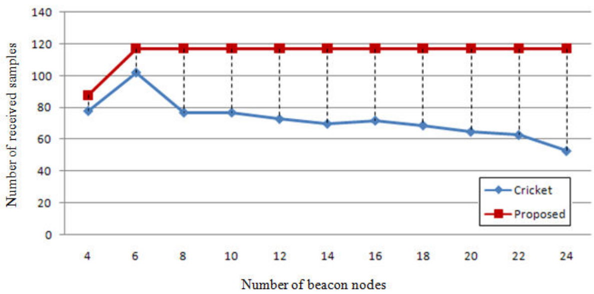

Fig. 12 Performance comparisons of the number of acquired samples

Fig. 13 shows the packet error rate according to the number of beacon nodes. In cricket, as the number of beacon nodes increases, the collision probability is increased and the number of received samples is decreased because all beacon nodes simultaneously transmit the RF signal and ultrasound signal. However, the proposed scheme using less beacon nodes can reduce the collision probability although using the Request Packet, Reply Packet, Solicitation Packet, and Polling Packet increases overhead. Consequently, our scheme achieves a low error rate as well as high accuracy because it receives the beacon signals from a small number of beacon nodes located closer to the listener node.

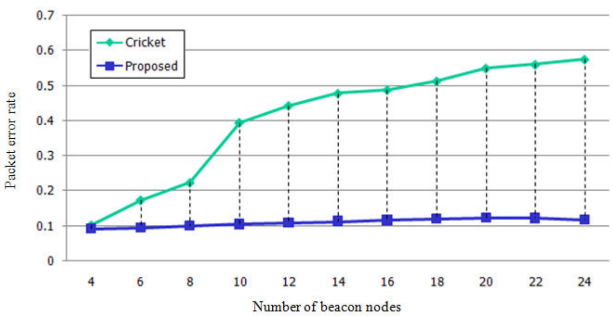

Fig. 13 Performance comparisons of packet error rates

Fig. 14 shows the received beacon ID in a mobile environment. The X-axis represents time and Y-axis represents the beacon location. In Cricket, the received beacon node is farther from the listener node compared to the proposed scheme. This result shows that the proposed scheme is able to achieve more accurate localization in a mobile environment.

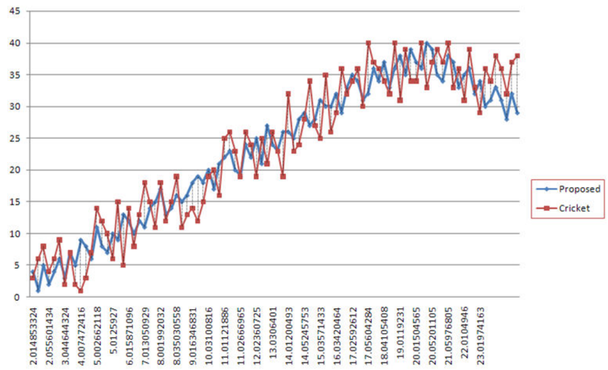

Fig. 14 Received beacon ID in mobile environment

Fig. 15 shows the average response time of localization. The time needed for receiving 4 beacons by Cricket is about 60 ms to 100 ms because cricket transmits the beacon using the random backoff mechanism. In contrast, the time needed by the proposed scheme is about 10 ms.

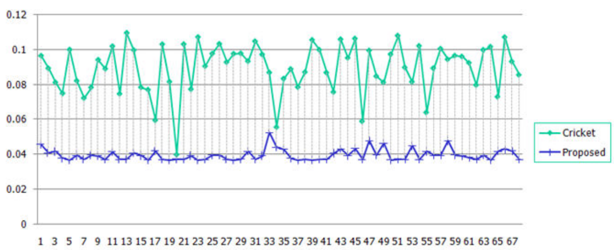

Fig. 15 The average response time of localization

6. Conclusion

Various applications that have network functions require human and object tracking in ubiquitous computing. Especially, there are many studies on location-aware applications for home network systems. For these applications, a sensor network localization system has been researched and a new Cricket system that is developed by MIT achieves high accuracy. To expand the localization space, many sensor nodes are deployed, creating much interference and collision. These interferences and collisions can degrade the performance of the whole localization system.

In this paper, we propose a localization scheme based on both the law of cosines and on-demand beacon management mechanism. In our localization scheme, the location of the listener node is measured by TDoA using only the two beacon nodes. We also propose an on-demand beacon management mechanism to minimize communication problems, such as collision and interference. The proposed mechanism can increase the probability of transmission chance from the nearest beacon and reduce the error probability that is affected by the characteristics of ultrasound. We implement the testbed of the proposed indoor location-based system using Cricket motes. Our testbed improves accuracy even though the testbed uses a small number of sensor nodes. We also evaluate the performances of the proposed localization and beacon management scheme by using the ns-2 network simulator. Our simulation results show that the proposed scheme achieves a lower error rate and lower response time than those of the traditional location-based system.

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