Abstract

Wireless geolocation techniques are of crucial importance for current and future dense wireless networks to support location-based services and applications requiring high accuracy. One of the challenging problems in wireless geolocation is to estimate the position of an unknown (anonymous) radio wave emitter. The location detection of unknown radio emitter is very important especially for helping people in disastrous situations; such as, finding the victims who are buried due to landslide, tsunami, and/or earthquake. It is also important for monitoring illegal radio emitter to prevent public broadcasting from being jammed.

In this research, factor graph-based techniques for geolocation techniques are considered the most promising candidates having several benefits; namely, (i) it decomposes the complex problem with many variables into a set of simple sub-problems with fewer variables, (ii) it operates in the form of mean and variance messages under the Gaussianity assumption of the measurement error, and (iii) it also requires only solving linear equations resulting significant reduction in computational complexity. It should be noticed that low computational complexity is of great importance for green technology to save the energy consumption. Furthermore, high accuracy is achieved by the factor graph because it effectively and efficiently performs statistical signal processing for probability marginalization.

The primary objective of this research is to propose novel algorithms of high accuracy and low complexity wireless geolocation techniques, based on the factor graph technique, to detect non-moving (static) position of a single unknown (anonymous) radio wave emitter. However, it should be emphasized that the proposed technique is not only applicable for unknown radio wave emitter, but also for general radio wave emitter position detections. In this research, three propagation parameters, i.e., direction of arrival (DOA), time difference of arrival (TDOA), and differential received signal strength (DRSS) are proposed, and their corresponding factor graph geolocation techniques are derived. Those techniques are suitable for solving the problems arising in each scenario for detecting the static position of single radio wave emitter.

In the presence of imperfect time synchronization with line-of-sight (LOS) condition, the DOA-based geolocation technique is known to be the best solution to the single static location detection. We consider factor graph geolocation technique, where the input is the samples of DOA measurement results sent from the sensors. This research proposes DOA-based factor graph (DOA-FG) with linear approximation of the tangent function so-called Taylor series DOA-FG (TS-DOA-FG), where the first order Taylor series expansion of the tangent is taken into account. It is shown that the accuracy of the DOA-FG geolocation algorithm can be improved by introducing approximated expressions for the mean and variance of the tangent and cotangent functions.

The TDOA-based geolocation techniques are known to be the most suitable solution in the presence of perfect time synchronization among the sensors. The proposed new technique, so-called Pythagorean TDOA-based factor graph (P-TDOA-FG), requires much less computational complexity compared to the conventional TDOA-based factor graph techniques employing hyperbolic function (H-TDOA-FG). The great improvement is due to the use of simple Pythagorean function, which is widely used in TOA-based geolocation techniques. The function is considered for the use of the conventional time of arrival (TOA)-based factor graph technique (TOA-FG). However, in practice, it is impossible for the TOA-based location identification techniques including the conventional TOA-FG to detect the position of the unknown target. This is because the TOA measurements require the knowledge of the absolute departure time of the signal, and this knowledge is unavailable.

The proposed P-TDOA-FG introduces several sets of new nodes and expressions into the conventional TOA-FG technique to convert the TDOA information from the measurements to the *equivalent* TOA information. The TDOA measurements do not require the knowledge of the absolute departure time information of the measured signal sent from the target. Hence, the *equivalent* TOA can be utilized in the modified TOA-FG to detect the position of the unknown target. The results have shown that the proposed P-TDOA-FG improves the accuracy of the conventional TOA-FG technique.

On the other hand, neither RSS-based nor DRSS-based geolocation techniques require the perfect time synchronization among the sensors and as well as between the target and sensors, array antenna, and knowledge of the absolute departure time of the signal sent from the target. In such conditions, the RSS and DRSS-based geolocation techniques are believed to be the most promising solution for the geolocation detection. However, the

conventional RSS-based factor graph RSS-FG) technique can not estimate the position of an unknown radio emitter because the technique requires the knowledge of the absolute value of the transmit power. Nevertheless, in practice, the transmit power information from the signal transmitted by the unknown target emitter is unavailable. It should be noticed that the knowledge of the transmit power is necessary for calibration/reference of linear approximation process using training signal sent from the monitoring spots. Thus, the DRSS-based factor graph (DRSS-FG) technique is proposed to solve the problem, where the necessity for the knowledge of the absolute transmit power of unknown target is eliminated. Hence, the DRSS-FG can estimate the unknown target.

Closed-form expression of the Cramer Rao lower bound (CRLB) taking into account of the number of samples, for DOA- and TOA- geolocation techniques, are also derived in this dissertation. An approximated CRLB taking into account of the number of samples, for TDOA-based technique, is also derived. The performance of the proposed technique is evaluated in terms of root-mean-square error (RMSE). The results show that the proposed techniques accurately estimate the location of unknown target, while they requires low computational complexity. It is shown that all of our proposed techniques achieve much higher accuracy compared to the conventional techniques. The achieved RMSE with the proposed techniques are also evaluated and found to be very close to the CRLB.

Keywords: Wireless Geolocation, Factor Graphs, DOA, TDOA, DRSS, TOA, RSS, CRLB, Voronoi Diagram, Unknown Radio Wave Emitter, Single Static Target