Received Signal Strength based Fingerprint Positioning in Cellular Networks involving Neural Networks and Tracking Techniques

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Foreword

The present dissertation results from research activities that I conducted at the Leibniz Universtät Hannover at the Institute for Communications Technology in the research group Positioning and Location based Services.

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Hannover, November 2007 Mbusa Claude Takenga

Abstract

Location estimation within cellular networks has been of increasing importance in the recent years. There is a broad agreement that localization will play a central role in enabling value-added services in the new generation cellular networks and that these services require different degrees of localization accuracy at low cost.

Densely built urban areas, where the mobile users' density is high, are in favour of commercial service providers. Thus, the possibilities of using location information are wide. In those areas, although high location accuracy is more valuable, the effects of multipath propagation of radio waves and non-line-of-sight situations are more significant.

Several positioning techniques based on direction-finding, range estimation and range-differencing have been developed. These conventional location techniques, based on either trilateration or triangulation, rely on line-of-sight path between the base station antenna and the mobile unit to be located. In densely built urban areas, this assumption is rarely valid. This fact degrades the location performance of the conventional techniques and motivates the need for development of more accurate technique suited for these areas.

The global positioning system (GPS) is an attractive solution for positioning. However, it is often inoperable in areas where satellites signals are blocked, such as in buildings and built-up urban areas. Further, the time-to-first-fix (TTFF) for a conventional GPS receiver from a cold start can take several minutes. Additionally, adding GPS functionality to handset can be costly, and drain battery power at an unacceptable rate. An alternative to conventional GPS, Assisted GPS (AGPS), shows promise of overcoming some of these limitations, but still new handsets should be applied. Consequently, positioning systems based on wireless communications infrastructures are still an important area of research.

A fingerprint-based positioning system was developed in this research. Such a method works better in the urban environment. Moreover, for its implementation, no additional equipments are required. All signal parameters needed are available in the existing networks, and they can be measured by the existing mobile terminals.

The main achievement of this research is the development of a low-cost Received Signal Strength (RSS) fingerprint-based positioning system working within cellular networks with an accuracy satisfying the requirements of several practical location-aware applications.

The fingerprint-based positioning system/concept developed in this dissertation can be divided into three sub-systems: (a) neural network based localization, (b) Tracking and (c) Map-Matching. The first and central sub-system copes with the problems related to fingerprint localization and involves a neural network (NN) as key element of the positioning concept. The time consuming collection of RSS values to gather sufficient training data is avoided by generating a prediction of RSS maps for the geographical area of concern. The generated RSS maps differ from real RSSs due to the fact that all propagation phenomena cannot be modelled properly. Thus, a calibration system was developed to correct the generated maps by a sample of real collected RSSs along the area of concern. The stochastic variation of the RSS levels was reduced by applying a time

delayed neural network, which performed a weighted average over a window as data were collected.

The positioning accuracy obtained from the first sub-system is still poor, i.e. an accuracy in the range between 70 and 200m (CEP-67). This is due to the inherent sensitivity of the RSS-fingerprints to the environmental changes that is still affecting the system. These relatively poor results motivate further improvement steps by post-processing the obtained location estimates. Tracking algorithms adapted to fingerprint-based cases were developed and implemented in the second sub-system. The tracking algorithm, based on Kalman Filtering, further reduced the positioning error in the order of 40m (CEP-67).

Furthermore, a scheme that discriminates between indoor and outdoor locations and a motion detection algorithm based on the RSS values were developed. These schemes could be applied for a further improvement of the locations estimated from RSSI based fingerprints. Moreover, a fusion of different approaches was implemented and appeared to perform better in terms of accuracy.

After reducing the positioning error, depending on the geographical structure of the environment, different methods were applied to map the estimated position to the nearby roads. That map-matching process is the task realized by the third sub-system and could further reduce the positioning error to approximately 30m (CEP-67). The obtained accuracy level does fulfil the requirements of a huge number of location-aware mobile applications and services.

During this research, special consideration was given to the following metrics: positioning accuracy, reliability of the system, and additional costs needed for implementing the developed positioning system in existing networks. The developed and tested positioning system produces performance results which satisfy the Federal Communications Commission (FCC) requirements for location of an E-911 caller (i.e. in emergency cases).

Keywords

Fingerprint-based localization based on received signal strengths, positioning in cellular networks, tracking, neural networks in positioning.

Kurzfassung

Es besteht heute keinerlei Zweifel daran, dass die Lokalisierung bzw. Ortungsinformation eine wichtige oder gar tragende Rolle im Ermöglichen von neuwertigen Mehrwertdiensten in Mobilfunknetzen der neuen und künftigen Generationen spielen wird. Diese ortsbasierten Dienste weisen unterschiedliche Anforderungen an der Genauigkeit der Ortungsinformation auf.

Dicht bebaute städtische Gebiete mit hoher Dichte an Mobilfunknutzern sind für kommerzielle Mobilfunkbetreiber von großem Interesse, da hier zahlreiche ortsbasierte Dienste möglich und gefragt sein dürften. Gerade in diesen Gebieten erweist es sich dennoch, leider, als Nachteil, dass die hier in stärkerem Maße vorhandenen Effekte der Mehrwegausbreitung und Abschattung zu einer Verschlechterung der Lokalisierungsgenauigkeit führen.

Konventionelle Funkortungsmethoden, welche entweder auf Trilateration oder Triangulation oder hyperbel-basietere Lateration basieren, bedürfen bzw. gehen von einer direkten Sichtverbindung zwischen der Basisstation und dem Mobiltelefon aus. In dicht bebauten, städtischen Gebieten ist diese Annahme jedoch selten gültig. Diese Tatsache hat eine signifikante Verringerung der Ortungsgenauigkeit konventioneller Methoden zur Folge und motiviert die Entwicklung, für diese Gebiete, von geeigneten und daher genaueren Ortungsansätzen.

GPS ist zwar die global unerlässliche Infrastruktur für Lokalisierung, ist dennoch in vielen Umständen nicht verfügbar bzw. wegen Abdeckungen nicht nutzbar. Dies ist insbesondere der Fall in stark bebauten urbanen Gebieten und innerhalb von Gebäuden. Bei einem kalten Start kann ein GPS-Empfänger zur Lieferung des ersten Lokalisierungsergebnisses bis zu einigen Minuten benötigen. GPS is also kein Allheilmittel für die Lokalisierungsbedürfnisse der zahlreichen ortsbasierten Diensten. Daher bleibt, als Ergäzung zu GPS, das Thema der Einbettung der Funkortung in den terrestrischen Mobilfunknetzen von großem Interesse für die Forschung.

Die in dieser Arbeit eingesetzte und optimierte Methode, die Fingerabdruck basierte Lokalisierung, weist neben der guten Genauigkeit einen niedrigen Kostenbedarf auf, da kein zusätzliches Equipment für die Implementierung in bestehenden Mobilfunknetzen benötigt wird. Ein besonderes Merkmal der auf Fingerabdruck basierten Lokalisierung ist es, dass sie die mit den bereits genannten Effekten der Mehrwegausbreitung und Abschattung besser umgehen und gar ausnutzen kann.

Das wichtigste Erreichen dieser Forschung, ist die Entwicklung eines kostengünstigen fingerabdruck Ortungssystems, die innerhalb von Mobilfunknetzen arbeitet mit der Positionierungsgenauigkeit, die FCC-voraussetzungen befriedigt.

Das entwickelte Ortungssystem kann in drei Subsysteme unterteilt werden: (a) Neuronale Netze als Kernbaustein des Systems, (b) ein Modul zum Tracking; und (c) ein Modul zum Map-Matching. Das erste Subsystem befasst sich mit der Verarbeitung und Speicherung des Fingerabdrucks und schließt ein oder mehrere neuronale Netze als Kernelement ein. Solch ein Ortungssystem, welches auf empfangenen Signalstärken als Positionsfingerabdruck basiert, ist gegenüber stochastischen Variationen der Signalstärken noch etwas empfindlich. Infolgedessen

ist die vom ersten Subsystem gelieferte Genauigkeit noch verbesserungswürdig (Genauigkeit in der Größenordnung von ca. 200m, CEP67). Dies weckt das Bedürfnis nach einer Nachverarbeitung. Tracking und Map-Matching sind daher notwendig und werden dann in einem zweiten bzw. dritten Subsystem durchgeführt, um die Ortungsgenauigkeit zu verbessern; das Ergebnis ist eine Genauigkeit in der Größenordnung von ca. 40m, CEP67.

Ein Algorithmus zur Bestimmung, anhand der empfangenen Signalstärken, ob sich ein Mobiltelefon draußen (outdoor) oder eher innerhalb von Gebäuden (indoor) befindet ist ebenfalls entwickelt und eingesetzt worden. Daraus ergibt sich ein weiteres Verbesserungspotential der Lokalisierungsgenauigkeit. Des Weiteren ist eine Fusion mit anderen Sensordaten erwogen und durchgeführt worden (Kompass, Inertial System), welche erwartungsgemäß zu einer Verbesserung der Robustheit und Genauigkeit geführt hat.

Zur Bewertung der Lokalisierungslösungen sind folgende Metriken in Betracht gezogen worden: Ortungsgenauigkeit, die potentiellen Kosten und die geschätzte Zuverlässigkeit des Systems. Das entwickelte und erprobte Ortungssystem liefert eine Genauigkeit und eine Zuverlässigkeit, welche die Anforderungen der meisten, gängigen ortsbasierten mobilen Dienste befriedigt. Die von der US amerikanischen FCC (Federal Communications Commission) festgelegten Anforderungen E-911 sind ebenfalls sehr gut erfüllt.

Schlagworte

Lokalisierung mithilfe eines auf Signalstärke basierten Fingerabdrucks, Lokalisierung in Mobilfunknetzen, Teilnehmerverfolgung (Tracking) und Map-Matching, Neuronale Netze für Lokalisierungszwecke.

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