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Wireless On-Demand Network Systems

First IFIP TC6 Working Conference, WONS 2004
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Proceedings

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Preface

This book contains the refereed proceedings of the 1st IFIP-TC6 Working Conference on Wireless-On-Demand Network Systems, WONS 2004. It was sponsored by the IFIP Working Groups 6.3 (*Performance of Computer and Communication Networks*) and 6.8 (*Mobile and Wireless Communications*), and aimed at becoming a premier international forum for discussions between researchers and practitioners interested in the evolution of Wireless Internet Access toward on-demand networking. Ad hoc, routing, localization, resource management, security, applications, performance and analytical models were topics covered in depth by technical papers in this book.

The conference received 77 submissions from 22 countries, showing the worldwide interest. With so many papers to choose from, the Technical Program Committee's job, providing a conference program with the highest quality, was challenging and time consuming. We finally selected 25 full papers for presentation in the conference technical sessions. To give researchers the opportunity to present the novel ideas they are starting to explore, we included in the technical program a poster session devoted to presenting preliminary research results: 7 short papers were selected for presentation in this session. Accepted papers and posters came from 15 different countries.

The technical program also included a keynote speech "Ad Hoc Wireless Networks: Protocols and Applications" by Prof. Mario Gerla, and a panel session devoted to the discussion of the conference topics between academics and industry representatives.

This event would not have been possible without the enthusiasm and hard work of a number of colleagues. A special thanks to the TPC members, and all the referees, for their invaluable help in reviewing the papers for WONS 2004. We would also like to thank all the authors who submitted their papers to this conference for their interest and time, as well as the Springer-Verlag LNCS staff, and Alfred Hofmann in particular, who helped to produce this volume with high standards.

Last, but not least, our very special thanks goes to the people in Trento who made the WONS 2004 event possible, and made this book a reality: Sandro Pera for his continuing organization, Mauro Brunato for solving most of the formatting problems (not only in the book) with creativity, Alessandro Villani for making things work every day and night, Erika Csép and Leonor Hernández Diaz for managing all WONS-related problems, including those of the colocated events relating to the EURO, INTREPIDO, TANGO, and VICOM research projects, and Elisabetta Nones and Paola Bodio for their logistics expertise.

November 2003

Roberto Battiti
Marco Conti
Renato Lo Cigno

Organization

WONS 2004 was organized by the "Computer Networks and Mobile Systems" Research Program of the Department of Informatics and Telecommunications (DIT) of the University of Trento, Italy, with the help of the Events and Meetings Office of the same university. WONS 2004 was sponsored by IFIP, through the Working Groups 6.3 and 6.8.

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Markov Localization of Wireless Local Area Network Clients

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Abstract. Markov localization has been successfully deployed in robotics using highly precise distance sensors to determine the location and pose of mobile robots. In this setting the scheme has shown to be robust and highly accurate. This paper shows how this approach has been adapted to the problem of locating wireless LAN clients in indoor environments using highly fluctuating radio signal strength measurements. A radio propagation model is used to determine the expected signal strength at a given position in order to avoid tedious offline measurements. Some of the issues that had to be addressed include expressing the calculated signal strengths in terms of probability density functions and detecting movement of the mobile terminal solely on the basis of radio measurements. The conducted experiments show that the proposed technique provides a median error of less than 2 m even when there is no line-of-sight to an access point.

1 Introduction

Geolocation systems in general can be based on a dedicated infrastructure or on an infrastructure designed for other purposes. The most popular approach to the latter is to use a wireless communication network. The spread of wireless LANs (WLAN) following the IEEE 802.11 standard [1] has consequently induced research on using the installed equipment for indoor geolocation purposes, as presented e.g. in [2], [3], [4] and [5]. Without modifications to the hardware of commercially available WLAN products such location systems must rely on radio signal strength (RSS) measurements to determine a mobile terminal's (MT) position. The measured RSS is commonly compared to reference values of a so-called radio map determined in the offline phase, i.e. before MT's are actually localized.

The WLAN location determination scheme proposed in this paper is based on the concept of Markov localization by Dieter Fox *et al.* presented in [6]. The idea behind this approach is to use discrete probability distributions to represent the MT's state space. To avoid time-consuming reference measurements the system presented in this paper uses a propagation model to create a radio map. The Markov localization scheme proves to be sufficiently robust to compensate

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for the errors introduced by the noisy wireless channel and by the propagation model. For real-world experiments its implementation has been integrated into the WhereMops location service introduced in [11].

The remainder of this paper is organized as follows. Section 2 describes the theoretical background to the proposed scheme, leaving some important – implementation specific – aspects open. These open issues will be tackled in Sect. 3, which introduces a new probabilistic radio propagation model, and Sect. 4, which presents the implementation details of the location determination system. Section 5 describes the evaluation process and the obtained results. Section 6 concludes the paper and gives a preview of possible future work.

2 Markov Localization

2.1 Motivation and Basic Idea

In recent years probabilistic localization schemes such as Markov and Monte-Carlo localization have gained increasing interest in the context of mobile robot systems designed for dynamic environments. Despite the fact that most mobile robots are equipped with rather precise distance sensor equipment deterministic approaches did not cope well in dynamic settings, e.g. with moving people or other objects not incorporated into the world model. Probabilistic approaches inherently model the uncertainties of real-world scenarios and can thus potentially achieve a higher robustness and accuracy.

The problem of dynamic environments also affects WLAN-based location determination systems, however such systems additionally suffer from highly inaccurate "distance sensors", meaning the measured received signal strength. Radio waves propagate in a very complex manner, the result being that even in a static environment one can observe so-called short term fading, i.e. fluctuations in the received signal strength. Furthermore even small displacements of the MT can significantly alter even the mean of the signal strength readings. The assumption at the outset of the work described in this paper, was that the Markov localization technique would prove sufficiently robust to cope with these adverse conditions, i.e. the dynamic office environment, the inaccurate sensor readings and the inaccurate world model provided by a propagation model, and yet deliver highly precise terminal locations.

Instead of maintaining a single hypothesis as to the MT's position, Markov localization maintains a probability distribution over the space of all such hypotheses. In the following this probability distribution is called belief. The belief about the MT's location is only updated when new perceptions are made (i.e. new RSS-measurements have been received) or after the MT has moved. The probabilistic representation allows the scheme to weigh these different hypotheses in a mathematically sound way.

2.2 Notation

Let L_T denote the random variable representing the location of the MT at time $t = T$ and $l = (x, y)^T \in L$ a specific position of the MT within the state space.

Following the notation used in [6] let $Bel(L_T = l)$ denote the probability, that at time $t = T$ the MT is located at a position $l \in L$. In the following the continuous probability distribution is approximated by a discrete, grid-based representation. Positions l that are located outside the grid have a probability of $Bel\,(L_T = l) = 0$. As $Bel\,(L_T = l)$ represents a probability distribution the sum over all grid cell values is $\sum_{l \in L} Bel\,(L_T = l) = 1$.

Finally let $S_T = \langle s_0, s_1, \ldots, s_T \rangle$ denote the temporally ordered list of all RSS-measurements and $A_T = \langle a_0, a_1, \ldots, a_T \rangle$ the temporally ordered list of all movements conducted by the MT up to time $t = T$.

2.3 Independence Assumptions

This section describes two essential independence assumptions which allow for an efficient recursive implementation of the Markov-Localization algorithm.

Independence of Actions. The state L_T at time $t = T$ solely depends on L_{T-1} and the last conducted action – i.e. movement – a_{T-1}. In other words, all previously reached locations, all sensory input and all previously conducted actions become irrelevant once the current state L_{T-1} is known. This is known as Markov-assumption and is summarized in the following equation:

$$P\,(L_T = l \mid L_{T-1},\, A_{T-1}, S_{T-1}) = P\,(L_T = l \mid L_{T-1}, a_{T-1}) \tag{1}$$

Independence of Sensor Input. A sensor reading s_T at time $t = T$ solely depends on the state of the environment at $t = T$. Once an MT's state space L_T is known, all previously recorded measurements, states and actions provide no additional information for the calculation of s_t. Equation 2 summarizes this predication.

$$P\,(s_T \mid L_1, \ldots, L_{T-1},\, A_{T-1}, S_{T-1}) = P\,(s_T \mid L_T = l) \tag{2}$$

2.4 The Sensor Model

The sensor model describes how to update the belief about an MT's position $l \in L$ at time $t = T$ given all previously recorded sensor readings S_T. This can be formulated as follows:

$$P\,(L_T = l \mid S_T) = P\,(L_T = l \mid s_0, s_1, \ldots, s_T)\,. \tag{3}$$

Using Bayes rule and Eq. 2 this can be transformed to

$$= \frac{P\,(s_T \mid L_T = l) \cdot P\,(L_T = l \mid S_{T-1})}{P\,(s_T \mid S_{T-1})}\,. \tag{4}$$

Obviously the denominator of Eq. 4 is independent of L_T and therefore constant. Furthermore it is assumed that the probability $P\,(s_T \mid L_T = l)$ for a sensor reading given a certain position is time-invariant. Hence, using $\frac{1}{\alpha_T} = P\,(s_T \mid S_{T-1})$ and the notation for $Bel(L_T = l)$ introduced at the outset, Eq. 4 can be rewritten as:

$$Bel\,(L_T = l) = \alpha_T \cdot P\,(s_T \mid l) \cdot Bel\,(L_{T-1} = l)\,. \tag{5}$$

This states that the updated belief about the location of an MT upon new sensory input, depends on the probability of the sensory input at a given position weighted by the assumed likelihood of being at this position.

2.5 The Action Model

The belief about the MT's position is not only influenced by the current sensor readings, but also by actions (i.e. movements) of the terminal. Thus there is a need to calculate the probability $P(A) = P(L_T = l \mid A_{T-1})$ that an MT at time $t = T$ is located at position $l \in L$, given all previously conducted movements A_{T-1}. Using the law of total probability this can be written as:

$$P(L_T = l \mid A_{T-1}) = \sum_{l'} P(A \mid B_{l'}) \cdot P(B_{l'}). \tag{6}$$

with $P(B_{l'}) = P(L_{T-1} = l' \mid A_{T-1})$ and $P(A \mid B_{l'}) = P(L_T = l \mid A_{T-1}, L_{T-1} = l')$.

Considering the assumption about independence of actions (Eq. 1) $P(A \mid B_{l'})$ can be simplified such that the probability is only dependent on the last conducted movement a_{T-1}. The term can be further simplified if it is assumed that the probability of reaching a location l given a location l' and an action a_{T-1} is time invariant.

$$P(A \mid B_{l'}) = P(l \mid a_{T-1}, L_{T-1} = l') \tag{7}$$

Resubstituting Eq. 7 in Eq. 6 and using the definition of $Bel(L_T = l)$ the influence of movements on the belief about the MT's location can thus be expressed as:

$$Bel(L_T = l) = \sum_{l'} P(l \mid a_{T-1}, L_{T-1} = l') \cdot Bel(L_{T-1} = l') \tag{8}$$

This states that the probability of being at location l after an action has been performed, can be calculated by summing up the probabilities of reaching l from l' given action a_{T-1}. Each addend is weighted by the likelihood of starting at position l'.

2.6 Algorithm

The previous section has presented the underlying principles of Markov-Localization. Equation 5 provides a recursive scheme for updating the desired density $Bel(L_T = l)$ when new sensor readings s_T are available. Complementary to this Eq. 8 provides the recursive definition of the update procedure when movement of the MT has been detected. The complete algorithm in pseudo-code is shown in listing 2.1.

So far four questions – all of which are highly dependent on the application environment – remain unanswered:

Algorithm 2.1 Markov-Localization

```
{initialize probability distribution Bel(L_{t=0})}
loop
  if new sensory input s_T available then
    if TravelledDistance ≥ Threshold then
      for all Locations l do
        {apply action model}
      end for
    end if
    for all Locations l do
      {apply sensor model}
    end for
    {normalize resulting distribution}
  end if
  wait Δt
end loop
```

1. How is $P(s_T \mid l)$ (Eq. 5) calculated, i.e. the probability of sensor readings depending on the location?
2. How is $P(l \mid a_T, L_{T-1} = l')$ (Eq. 8) calculated, i.e. the probability of reaching one location from another given a movement?
3. How is movement detected based on RSS measurements?
4. How should the density function for $Bel(L_{t=0})$ be initialized?

All questions are answered in Sect. 4 which describes the implementation details of the Markov localizer. First however the automatic creation of radio maps is discussed, as this is an important prerequisite for the location determination system.

3 Computing Radio Maps

In order to calculate the likelihood of a signal strength measurement given a certain position and base station, the system needs to know what to expect. Radio (signal strength) maps are commonly used to associate reference positions with their expected radio signal strength. The simplest way to build a radio map is by conducting measurements for a set of reference points, with the obvious disadvantage being its enormous costs in terms of time. Trivially the positioning accuracy depends on the distance between the chosen reference points. For example, a desired positioning accuracy of 2 m on one floor of the computer science department building depicted in Fig. 1 would require approximately 300 measurements. Should the floor plan change or an access point be relocated these measurements would have to be repeated. In essence the empirical creation of radio maps is impractical especially considering large-scale deployment of location-based services.

A different approach to generating a radio map given a floor plan is to employ radio propagation models, which are frequently used to plan wireless communication networks. The advantage of calculating instead of measuring the radio