Local positioning services on IEEE 802.11 Networks

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Abstract

This paper deals with localization services in IEEE 802.11 networks. The proposed solution processes the Time Of Arrival (TOA) of location packets sent by any Mobile Terminal, received by the Location Supporting Nodes (LSN) and the Location Support Server (LSS) that compose the location services architecture. A fully compatible IEEE 802.11 Localization Services protocol supporting data exchange related to both TOA measurement and processing is reported. Simulation results show the method efficiency in both IEEE 802.11 PCF and DCF modes. Assessment of the maximum number of MTs for which location services can be provided is also reported. Since high localization accuracy requires large bandwidth, a broadband antenna for LSN and LSS was designed. The related results are reported in the second part of the paper. Antenna was tested by HP 8510 Network analyzer for the s-parameters, and by anechoic chamber for the radiation pattern and polarization purity. The antenna works at 5.0 GHz (centre frequency) in broadband mode and is matched on the wire less operating frequencies with a percentage more than 8% (1:1.5 VSWR).

1. INTRODUCTION

Wireless networks represent the main support for mobility user. In next generation architectures, end-to-end communication is often provided by cooperation between mobile nodes in the network. Each node needs to know the location of the destination and those of its neighbours to make forwarding decisions. In this scope, network based localization services can be of primary interest, specially in those environments where satellite positioning systems are not available. Localization services are acted on the basis of instantaneous bandwidths matched to the required accuracy.

Moreover, location information is essential for many other applications like habitat monitoring, homeland security, search and rescue, navigation aid, info mobility, sensor network organization, and information about locally available resources [1].

The aim of this paper is twofold. First, we illustrate a Time Of Arrival (TOA) based scheme for localization services in IEEE 802.11 networks. Then, we describe an antenna for IEEE 802.11 nodes designed for accurate location estimation. Microstrip antennas have evolved from simple single patch structures to complex multilayer configurations comprising of multiple feeds and active elements [2]. These antennas are attractive candidates for wireless communication systems because of their conformal low-profile, lightweight characteristics and the ease with which they can be integrated with feeding networks and associated circuitry.

In Section II we describe the localization procedure in detail. In Sections III an assessment of the maximum number of served units and the simulation results are presented.

Then, Section IV and V introduce the fundamentals of Wi-Fi adaptive antennas and our microstrip solution. Section VI concludes the paper.

2. LOCALIZATION SERVICES IN IEEE 802.11

Local Positioning Systems (LPS) deploy a grid of RF nodes that communicate with devices and then triangulate to determine their locations. Several methods in IEEE 802.11, Bluetooth, and RFID networks rely on the estimate of the user distance based on the amplitude of the signals received by each node. Besides their simplicity, these techniques perform rather poorly, since in complex environments the received signal is prone to fading induced by multipath.

For this reason, we devised a solution that makes use of the Time Of Arrival (TOA) of a location packet broadcasted by the Mobile Terminal (MT). More specifically, the proposed architecture consists of a grid of Localization Supporting Nodes (LSN) and a Localization Support Server (LSS). The main tasks of the LSS are: registration of incoming MTs, distribution of synchronization signals, coordination of TOA measurement, TOA measures collection, location estimate, and location notification.

On the other hand, each LSN is based on the measurement of the TOA of the location packets sent by the MT. In applications demanding high location accuracy, to meet the consequent instantaneous bandwidth requirement, use of IEEE 802.11 a or IEEE 802.11 g is recommended.

In principle, in IEEE 802.11 networks, both the measurements and the broadcast of the estimated position of several mobile terminals (MT) can be performed using either PCF (Point Coordination Function) or DCF (Distributed Coordination Function) medium access control (MAC) modes, [3], [4], and [5].

In the first case the Access Point (AP) acts as Point Coordinator (PC), while in the second one the control is decentralized among peer nodes.

Exploiting the PCF mechanism the system is able to provide near isochronous polling request to the MT
avoiding the collisions typical of the DCF mode. Thus, to warranty the Quality of Service (QoS) of location services, as well as the QoS of any other real time service provided by the network (e.g. VoIP), we resort to the PCF mode to periodically update the estimated location of each registered MT at a rate that depends on the MT mobility class.

Consequently, to reduce the coordination overhead, the LSS functionalities are provided by the AP, [6].

Let us now describe the main parts of our localization algorithm. The AP periodically broadcasts a Localization Services Support advertisement. A new MT entering the AP coverage area, interested on localization support, sends a Localization Services Registration Request, specifying its mobility class and the update interval. The AP verifies whether the MT can be admitted to the service, then inserts the MT in the Location List and sends back to the MT a Localization Services Registration Confirmation. The subscribed MTs are then periodically queried by the AP during the PCF phase to broadcast a Location Packet which is then used by the LSS nodes to estimate their distance from it. Thus, the location procedure consists of five steps:

1. **Location Update Request (LUR):** when the update interval associated to an entry of the Location List is elapsed, the AP sends to the corresponding MT a LUR packet.

2. **Location Packet Broadcasting:** when the MT receives the LUR packet from the AP, it broadcasts a Location Packet including a time stamp during the CF-UP phase of the PCF.

3. **MT-LSN TOA Measurement:** after successfully received the MT Location Packet, each LSN estimates the TOA.

4. **Collect:** the LSNs transmit back their TOA measure set to the AP during the DCF phase. In order to save bandwidth usage, each LSN can send in a single data packet multiple TOAs for different MTs.

5. **Location Computation:** when the AP receives the LSN data, it computes the MT location and resets the update timer. At least three distance estimation are needed to calculate the user position.

The overall process is cyclic and repeats at the multiple of Location Update Interval, typically a multiple of the super-frame duration. Of course, multiple users are localized during the same super-frame. In case of congestion users are distributed on different super-frame and update rates are eventually reduced. In presence of problems in the overall process, the position estimation is postponed to the next scheduled instant.

### 3. Maximum Number of MT Estimation

In order to evaluate the maximum number of users that can be served by an LSS, we observe that time frame necessary to poll a user, to receive back the broadcast packet and then to calculate the user position is:

\[
T = 2 \frac{r_{\text{max}}}{c} + 2T_{\text{SIFS}} + \frac{D_{\text{LUR}} + D_{\text{ACK}}}{B} \tag{1}
\]

where \( r_{\text{max}} \) is the maximum distance served by the LSS [m], \( c \) is the speed of light [m/s], \( T_{\text{SIFS}} \) is the SIFS interval duration, \( D_{\text{LUR}} \) is the Location Update Request packet size [bit], \( D_{\text{ACK}} \) is the Acknowledge packet size [bit], and \( B \) is the Data Rate [Mbps]. Thus, the number of users that the system is able to manage within one super-frame (PCF+DCF) is given by:

\[
N_{\text{TOT}} = \frac{\Delta T_{\text{DCF}} - T_{\text{SIFS}} + D_{\text{BEACON}} + D_{\text{CFEND}}}{B} \times \left( \frac{r_{\text{max}}}{c} + \frac{D_{\text{LUR}}}{B} + T_{\text{PIFS}} \right) \tag{2}
\]

where \( \Delta T_{\text{DCF}} \) is the maximum duration of the PCF [ms], is the BEACON packet size [bit], \( D_{\text{CFEND}} \) is the CF-END packet size [bit], \( T_{\text{PIFS}} \) is the PIFS interval duration, and \( \varepsilon \) is the performance reduction factor due to the coverage area and channel noise.

Combining Eq. (1) and (2), the maximum number of users the network is able to manage is:

\[
N_{\text{TOT}} = \frac{\Delta T_{\text{POLL}}}{\Delta T_{\text{SUPERFRAME}}} \frac{1}{\mathfrak{S}(N)} \tag{3}
\]

where \( \Delta T_{\text{POLL}} \) is the polling period of the same MT, \( \Delta T_{\text{SUPERFRAME}} \) is the super-frame duration and \( \mathfrak{S}(N) \) is the integer part of \( N \). As stated previously, \( N_{\text{TOT}} \) is strictly related to the LUR time and hence to the mobility class of the users.

To evaluate the performance, we simulated a multiple mobile terminal scenario with 6 LSNs located on the hexagon vertex and one AP in the hexagon center, as Fig. 1 depicts.

**Fig. 1.** 7 BS (LSN + 6LDSN) grid configuration, 36m x 32m.

The operating frequency is 2.4 GHz, according to the IEEE 802.11g standard. The coverage area was set to the maximum distance between the LSN and the AP. The size of data packet used to poll the mobile terminals was fixed to 400 bit and the ACK packet size to 112 bit, according to IEEE 802.11 standard.
The time parameter necessary to transmit a single packet was expressed as:

\[ T_{\text{packet}} = T_{\text{computation}} + T_{\text{transmit}} \tag{4} \]

Assuming the computation time is negligible, it results \( T_{\text{packet}} = \frac{L_{\text{packet}}}{M} = \frac{400 \text{ bit}}{12 \text{ Mbps}} = 0.033 \text{ms}. \) Thus, the time necessary to transmit a packet is a function of the data rate. Assuming low speed users (1-2 m/s), a good compromise for the LUR rate is 500ms.

According to IEEE 802.11 standard, in our simulation we set: SIFS = 28μs, PIFS = 48μs, DIFS = 68μs, Minimum Contention Window period = 16μs, Maximum Contention Window period = 4080μs, Superframe duration = 5ms.

We set the MTs speed magnitude equal to 2m/s and the LUR period to 0.5s. The data rate range spans from 6 Mbps to 26 Mbps, while the BS coverage area was fixed to the maximum value specified by the IEEE 802.11 standard for the specific data rate in indoor environment. For each case different paths have been simulated, varying the MT initial position and motion direction, in order to consider the statistics of at least 1000 different points of the grid.

The output results were evaluated in terms of AP waiting time, necessary to perform position estimation, from the moment the AP queries the MT to the time it receives back the LSN estimations. Then, the average number of available LSNs in the MT covered and the number of actually used LSNs were evaluated. Finally, location probability expresses the probability that the AP has at least three distance estimations on which to perform the triangulation.

Respectively, Fig. 2, Fig. 3, and Fig. 4 depict the AP Waiting Time, the number of LSNs used and the Location Probability as function of the number of MTs for four different data rate/coverage area values.

Fig. 2 shows that the AP Waiting Time increases as soon as the number of MTs increases. The main cause for that is the number of collisions increasing. On the other hand, the number of used LSN decreases, since the LSNs have to send longer packet (containing more TOA estimations) during the DCF phase, causing an additional increase in the number of collisions.

Regarding the Location Probability, Fig. 4 shows that to achieve better performance it is more important to have a higher coverage area rather than a higher data rate. Finally, with an average Location Probability of 80%, the AP receives at least three distance measures for each of the 25 MTs for a LSNs coverage area greater than 25m, while the number of localizable MTs drops to 17 for LSNs coverage area less than 25m.

4. WIRELESS MICROSTRIP ANTENNAS

In this Section an innovative antenna configuration for “indoor” use and the consequent realized “breadboard” model are shown. Although the initial microstrip antenna designs involving single patches had narrow impedance bandwidths, low polarization purity, poor power handling capabilities, and spurious feed radiation, several new configurations have been proposed to offset these limitations.

Mobile communications demands numerous types of antennas with multi-band, agile polarization, agile beam control, in-built diversity capabilities, and compatibility with EMC. Then, static in-building wireless systems promise equal massive demands for “smart” user-friendly antennas.

A narrow bandwidth is a disadvantage of microstrip antennas. For wireless communication systems, the required operating bandwidths are about 7.6% for GSM, (890-960MHz), 9.5% for DCS, (1710-1880MHz), and 12.2% for UMTS, (1920-2170MHz). To meet these bandwidth requirements, many bandwidth-enhancement or broadband techniques for microstrip antennas have been reported recently [7]. Dual-polarized operation has been an important subject in microstrip antenna design and finds application in wireless communication systems.
that require frequency reuse or polarization diversity. Microstrip antennas capable of performing dual-polarized operation can combat multipath effects in wireless communications and enhance system performance [7].

Compact microstrip antennas capable of dual-polarized radiation are very suitable for applications in wireless communication systems that demand frequency reuse or polarization diversity. Then, dual-frequency microstrip array can find applications in base-station antenna designs for wireless communications since it can have a narrower beam-width radiation pattern in the elevation direction and a broadside radiation pattern with a wide beam-width in the azimuthal direction.

5. LSN AND LSS ANTENNAS

In Fig. 5 a possible candidate for LSN and LSS Antenna is shown. Antenna electrical design has been performed by commercial electromagnetic 3D software. Antenna has been tested by HP 8510 Network analyzer for the s-parameters, and by anechoic chamber for the radiation pattern and polarization purity. The antenna is designed to work at 5.0 GHz in broadband mode in RHCP; however, by a proper dimensioning of the slots, resonating frequencies can be steered, so the antenna can work in dual frequency mode [7].

Respect to a “standard” patch antenna the proposed single element appears more compact (effect of the slots on the resonating frequencies). Antenna is matched on the wireless operating frequencies and the percentage is more than 8% (1:1.5 VSWR) considering f = 5.0 GHz as the centre frequency.

The polarization purity is less than -25 dB at boresight, -20 dB at the edge of coverage [-15°; +15°]. This low value of crosspolarization is achieved by the use of the “sequential rotation” technique, as it can be observed in Fig. 5.

In order to have a precise control of amplitude and phase of every element excitation coefficients, hybrid couplers and Wilkinson dividers have been adopted. They assure low coupling levels between branch outputs preventing any undesired reflection due to eventual single element malfunction/mismatching. Antenna gain level is 12 dBi at centre frequency (fixed beam). The radiation pattern beam-width radiation is narrow [-10°; +10°] in the elevation plane and wide in the azimuth [-45°; +45°] plane. The side lobe level is less than -12 dB.

Mutual coupling level is less then -20 dB between two adjacent patches, -30 dB for not adjacent elements. The antenna is also low cost, and easy to be fabricate and microstrip technology ensures a lightweight and ease-to-integrate with other circuitry. Cost and fabrication, repeatability and integration with other components are easy issues, as requested for indoor use.

Finally, the adopted Kevlar material assures light weight and contained losses. For the above reported performances this microstrip antenna is more than an adequate candidate for 802.11 applications.

6. CONCLUSION

Our aim is to complement WLAN networks with location services for indoor environment. In the first part of the paper, an innovative technique for localization purpose in IEEE 802.11 networks was investigated. Simulation results show the algorithm is able to locate all the users with low mobility. Then, in the second part of the paper we present a design of microstrip antenna for LSN and LSS nodes.

The location algorithm and the tracking model for user position are going to be validated by proper test campaign (“proof of concept”) whose scenarios definition is in progress. It will be part of future papers. In this frame, LSN and LSS antennas configuration has been identified and tested.

Future works will also implement the localization algorithm in WiMax networks and best performances are attempted for outdoor or open indoor environments, (i.e. airports, train stations, museums, etc.).

7. REFERENCES