LOCATION TRACKING FOR MEDIA APPLIANCES IN WIRELESS HOME NETWORKS

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ABSTRACT

We present a location detection system for tracking multimedia appliances and users within a wireless local area network (WLAN) enabled home environment. Multimedia appliances communicate with a central gateway via low cost network interface devices called Buddies. The gateway can locate the users and appliances within the accuracy of a room and use the location information to automatically redirect media streams to user’s presence. We call this paradigm as a Media cloud. This paper presents the scheme for collecting proximity information from the buddies and effective techniques to determine their location. We have implemented the location detection system and present an experimental performance evaluation.

1. INTRODUCTION

Wireless Local Area Networks (WLANs) based on the IEEE 802.11 standard are becoming popular both in enterprise and the residential environment. Their success can be attributed to the twin benefits of minimal infrastructure and high bandwidth capacity, making them a natural choice for home environments. In the future, WLANs in homes can play a much bigger role than simply connecting computers. Multimedia appliances such as DVD players, audio speakers and TVs will also be wireless enabled - i.e. they can utilize the wireless network for control and data communications. Such a ubiquitous wireless home media network can transform media appliances into mobile plug and play devices. Our goal is to enable such home WLANs to provide what we call as a Media cloud that follows the user automatically. We present a novel technique for tracking the location of appliances and users within the WLAN home environment. We can accurately locate the current room of the appliance in a home without the need for specialized equipment on the WLAN network. The system can transparently coexist in the WLAN network.

Figure 1: A WLAN home network. Media Appliances connect to the Actiway through the Buddies.

Our location tracking system frees the user from being constrained by location. The system can provide novel features such as mobile media clouds and location aware multimedia streams. A mobile media cloud is a set of active media streams that automatically follow the user in the home. For example, when the user moves from the living room to the bedroom, the media playing in the living room TV switches to the bedroom TV. This feature provides continuity of media content and streams by switching between appliances. Location aware media streams can maximize the utility of media appliances. For example, the system can get alerted when the user moves to her car in the garage and instantaneously cache into her car, the music she had been listening to, in her room earlier.

The architecture of WLAN enabled home environment is illustrated in Figure 1. The central control unit in this architecture is called the Actiway (short for Active Gateway). It serves as an intelligent...
control and media switching unit between the WLAN enabled appliances in the home. Each of the media appliances in the home connects to the home WLAN via an interface called a Buddy. The buddy is equipped with a codec for the media type of the appliance that it supports. The buddies are lightweight, inexpensive, and do not have specialized hardware for location detection. A media appliance with its buddy will be referred to as a media device (or simply device) in this paper. In addition there is a Remote control device to transmit commands over WLAN to the gateway, so as to control all the media devices. The remote is a low power, low bandwidth device compared to the buddies since it is used only for control. Both the buddies and the remote control are accurately and automatically located within a home by the techniques we present in this paper.

The rest of the paper is organized as follows: Section 2 surveys related work. Section 3 provides an overview of the design goals, the architecture, and algorithms for location detection. Section 4 presents implementation and experimental evaluation. Section 5 concludes the paper.

2. RELATED WORK

In this section we cover some general background of location detection in wireless environments. We will examine why much of the existing work in location detection cannot be adopted in a home environment. Most existing location detection techniques over wireless networks use the signal strength metric for determining the distance between nodes. Signals, through which nodes communicate, propagate as waves in the air which are subjected to attenuation and fading. This property of the signals is exploited to determine the distance between the two nodes. Mathematically signal propagation is defined as $P_r = P_i \frac{\lambda^2}{(4\pi d)^2}$ where $P_r$ is received power, $P_i$ is transmitted power, $\lambda$ is a constant and $d$ is the distance between the sender and receiver. This analytical model of signal strength does not correlate very well with practical situations. This is because there are a lot of other factors like reflection, refraction, absorption and obstruction which make the signal vary over a wide range.

One of the popular technologies for location detection is the GPS system. This system uses the triangulation information from three reference points to locate the node. The biggest disadvantage with GPS is that it does not work indoors and commercial systems have accuracy ranging over 10 meters and above.

Location detection in wireless networks, particularly 802.11, has been widely researched. RADAR [1] is a location detection scheme for infrastructure wireless networks. The technique uses signal strengths recorded at various access points and triangulates the location of a node. The system requires the presence of at least three access points to locate a node. In contrast, a home environment is characterized by a single access point. Similar location schemes are also proposed in ad-hoc networks [3] where the signal strength is translated into a distance vector, and is used to construct the location topology. These schemes use an analytical model for signal strengths, which are known to be very inaccurate due to multipath fading and presence of objects in the line of sight. Hence none of them are applicable to a home WLAN environment.

3. DESIGN AND ARCHITECTURE

3.1 Design Goals

Our location detection system is targeted for tracking media devices and users within a home. The system is designed to locate within the accuracy of a room. The system groups all of the media devices in a room into a proximity set. The system uses proximity knowledge to determine nearness of media devices. This proximity value is denoted by $\mu(i,j)$ and its numerical value is measured to be the strength of the signal from media device $j$ to $i$. These signals are generated and received by the Buddies. The user's movement is tracked with the help of the remote which also generates signals. The user is assumed to carry the remote with her as she changes her location within a home.

The design goals of the location system are as follows:

1. Locate the room to which a media device belongs.
   - The system does not need an absolute geographical coordinate: accuracy is limited to standard room dimensions.

2. The system should accurately locate without the need for detailed configuration information like dimensions of the house or a pre-computed signal map.

3. The technique for generating and recording proximity between media devices should be non-intrusive, i.e. this mechanism should not interfere with the normal functioning of the device which is to transmit/receive media. For example, media devices cannot stop playing and help in location detection.

4. The system should employ good algorithms to help precisely locate a device in its room in the face of variations over obstructions - both static furniture and moving objects. Some of the biggest problems in using signal strengths are the unpredictable variations...
variation due to moving objects and the lack of line of sight.
5. The technique should be simple, easy and, since the Actiway needs to regularly update locations of the devices, the technique should converge quickly.
6. The system should be able to track devices in the face of their being moved between rooms. The remote carried by the user is a highly mobile device whereas media devices such as, audio speakers and DVD players could also be moved albeit less frequently.

3.2 Architecture
Consider a home environment with 1 ... N. Let us denote each of these rooms as Rm for all m < N. In the steady state we assume that devices b1 to bn have already been located in the rooms R1 to Rn. When a new device b_{n+1} enters a room, it needs to be located. The new device b_{n+1} broadcasts a locate beacon on the WLAN network. All previously located devices listen for the beacon announcements from new devices. When a device d1 receives a locate beacon, it registers the beacon with its proximity value. Further b1 sends this information with its current location and identity to the Actiway. Using the information sent from all the devices, the Actiway generates a square matrix M[k+1,k+1] where each element \( \mu(i,j) \) represents proximity of j as received by i. Each row corresponds to a receiving device and each column corresponds to a transmitting device. The functioning of our location tracking system is based on three new techniques:
1. Incremental convergence: As more and more multimedia devices are added to each room, the number of receiving devices increases. As the number of devices in the system increases, we have more reference points and hence the prediction can converge to the actual location.
2. Room proximity: the proximity value \( \mu(i,j) \) for all devices i which are in the same room as the new device j, is much larger than for the devices in another room. This is due to walls, doors and ceilings between rooms which attenuate signals.
3. Dominant neighbor: Within a room there is a good chance that for some device i in the same room as the new device j, the \( \mu(i,j) \) is very strong compared to that received by all other devices. This is generally because devices i and j are next to each other or there is a direct line of sight.

Combining the above three as foundations we have derived a technique called Proximity Amplification. The algorithm uses the location matrix and the location information of each device. Exploiting room proximity, the algorithm calculates a location rank for each room which indicates the likelihood of the room containing the new device. This rank is then compared between rooms and the one with the highest rank is the room in which the device is located. The location rank (LR) for room Rm is computed as follows:

\[
LR_{Rm} = \frac{\sum_{\forall \text{devices } j \in Rm} wss(j, i)}{\text{Count}(Rm)}
\]

where

\[
wss(j, i) = \mu_{\text{max}} - (\mu_{\text{max}} - \mu(j, i)) \times \frac{\mu_{\text{max}} - \mu_{\text{min}}}{\mu_{\text{max}} - \mu_{\text{min}}}
\]

where j denotes the new device, \( \mu(i,j) \) is the weighted proximity value, \( \mu(i,j) \), Count(Rm) is the number of existing devices in room Rm, \( \mu_{\text{max}} \) and \( \mu_{\text{min}} \) are the maximum and minimum signal strengths, respectively, recorded in room Rm. The dominant neighbor’s proximity value of room Rm (which is \( \mu_{\text{max}} \)) is amplified in the rank calculation of that room by making the difference between \( \mu_{\text{max}} \) and the remaining proximity values smaller. The effect of this amplification is highlighted in fig. 2. This increases the influence of \( \mu_{\text{max}} \) on the rank of a room. The room with the highest rank is the room in which the device j is located.

![Figure 2: A comparison of Amplified proximity values and original values. A sample set of five values (\( \mu_{\text{max}}, 1, 2, 3, \mu_{\text{min}} \)) and the corresponding amplified values (\( \mu_{\text{max}}, 1', 2', 3', \mu_{\text{min}} \)) are shown on the axis. As seen all the values except \( \mu_{\text{min}} \) shift towards \( \mu_{\text{max}} \) (the maximum proximity value) in the amplified row.](image)

The complete algorithm is presented in fig. 3. It takes the matrix M and the id i of the device to be located. It returns the room that contains the device i within it. Let Set(Rm) = \{\mu\{1, i\}, ..., \mu\{j, i\}\} be the set of all proximity values recorded in the j devices of Room Rm. min(Set(Rm)) is the minimum of the values contained in the set and max(Set(Rm)) be the maximum of those set. A special case arises when the first device enters a room. Since there are no room neighbors for this device, its location needs to be configured by the user. Any device which enters the room after this stage can be located by the proximity amplification algorithm. An interesting aspect of the problem is the generation of the
locate beacons. The system could be constantly monitoring the location or it could be user activated, depending on the mobility.

\[
\text{PAH}(M, i) \{
\text{for each Room } R_m \text{ do}
\quad \text{for each } k \text{ in } \text{Set}(R_m) \text{ do}
\quad \quad \text{weighted } \text{Set}(R_m)[k] = \text{max} \left( \text{Set}(R_m) \right) + \left\{ \text{max} \left( \text{Set}(R_m) \right) - \text{Set}(R_m)[k] \right\} \times \text{max} \left( \text{Set}(R_m) \right) - \text{min} \left( \text{Set}(R_m) \right)
\quad \text{LR}(R_m) = \text{Rank} \left( \text{weightedSet}(R_m) \right)
\quad R_{\text{max}} = \text{max} \text{ for all } R_m \left( \text{LR}(R_m) \right)
\quad \text{return } R_{\text{max}}
\}\]

*Figure 3: The Proximity Amplification Algorithm for location detection.*

4. IMPLEMENTATION AND EXPERIMENTAL EVALUATION

In this section we present an experimental evaluation of the proximity amplification technique. We implemented this system over the 802.11b wireless network. Laptops with Lucent Orinoco wireless cards served as media devices. The mobile remote was implemented on an 802.11b enabled PDA.

The setting was in a two bedroom apartment (fig. 4). The apartment had all the standard media appliances like TVs, DVD players and PCs, cordless phones, microwave ovens (known to cause interferences with WLAN signals). The beacons were 802.11 management packets, broadcast at periodic intervals of 100 ms. Each packet carried a beacon id which identified the transmitting device.

The remote was carried around in the home to 10 different locations marked in Fig. 4. At each of these locations, beacons were transmitted and recorded at the six devices. At the end of the experiment the information from all the devices were collected and tabulated (fig. 6).

To illustrate the working of proximity amplification technique let us consider location four (L4 in fig. 5). The proximity rank for room one is -57: room two is -45: room three is -65. Since room two has the highest proximity rank, the location result is room. As seen the results are exceptional in all cases. Some of the locations like L12 were chosen specially to test the algorithm for boundary cases.

![Figure 4: A Layout of the home. L1 … L10 denote the locations of the remote (i.e. the user as she moves around). b1 … b6 denote the locations of media devices.](image)

![Figure 5: The first six rows store the signal strength recorded at each device from the remote. The 7th and 8th rows show the predicted and actual room numbers.](image)

5. CONCLUSION

We have developed proximity amplification technique for location detection for multimedia devices in the home environment. Such a system enables a media cloud that moves like an information shadow with the user. We have also developed architecture for connecting media appliances to a home gateway through interface devices called Buddies. The technique was implemented and tested in a real home and the results are excellent for room-wide accuracy of media device location.

6. REFERENCES