The Potential for Location-Based Services with Wi-Fi RFID Tags in Citywide Wireless Networks

Henrik Ljøgodt Moen #1, Thomas Jelle *2

#*Department of Telematics, Norwegian University of Science and Technology*
NTNU, NO-7491 Trondheim, Norway
1henriklj@stud.ntnu.no

**Trådløse Trondheim AS*
O.S. Bragstads plass 2B, NO-7491 Trondheim, Norway
2thomas.jelle@item.ntnu.no

***Abstract*— Active Radio Frequency Identification (RFID) tags that comply with IEEE 802.11 standards are currently used within indoor Real-Time Location Systems (RTLS) in several niche markets. With the rapid deployment of citywide wireless networks, outdoor Location-Based Services (LBS) have become an important research area. Such services are believed to have a considerable business potential in citywide wireless networks. Wi-Fi RFID tags can be used to take advantage of such a potential. However, very limited testing has been carried out in order to examine the performance of the Wi-Fi RFID technology in outdoor environments. In this paper, the authors present results from the testing of Wi-Fi RFID tags within the citywide wireless network deployment Wireless Trondheim (Trådløse Trondheim). The location-based solution used in the deployment has explicitly no support for determining location in outdoor environments. Still, it is important to survey the current performance of the Wi-Fi RFID technology in order to identify the potential for commercial services. The results presented in this paper indicate several limitations with this technology in citywide wireless networks. These limitations constrain the current possibilities for commercial services based on Wi-Fi RFID tags in Wireless Trondheim.**

I. Introduction

The Radio Frequency Identification (RFID) technology is attracting considerable attention these days, in both research and business communities. RFID tags can either be active or passive, depending on their source of power. Active RFID tags are characterized by having their own internal power source, in general a battery. Unlike passive RFID tags, which must be within the radio frequency (RF) field of an RFID reader to get the needed transmission power, battery-powered tags can transmit from outside the RF field, and hence at a much greater range.

Active RFID tag systems are commonly used within logistics, transportation and supply chain management [1]. These systems have initially been based on vendor specific solutions, where proprietary receiver units are used in the infrastructure. However, over the past five years, a new category of active RFID tags that comply with IEEE 802.11 standards, has been adopted in niche markets. These tags, known as Wi-Fi RFID tags, can be identified and located using regular Wi-Fi access points. These access points are inexpensive and easily available, resulting in cost-efficient solutions for Location-Based Services (LBS).

Wi-Fi RFID tags are available from manufacturers like AeroScout [2], Ekahau [3], PanGo [4] and Radionor Communications [5]. In the healthcare industry these tags are utilized in hospitals to locate expensive medical equipment as well as patients and staff [6]. Wi-FI RFID tags are proven to work well in indoor wireless networks, with a location accuracy less than or equal to 10 meters [7]. With the rapid deployment of city-wide wireless networks around the world [8], outdoor Location-Based Services (LBS) have become an important research area. However, a reasonable accuracy can be hard to achieve in outdoor environments. Factors like lower access point density and the use of external antennas tend to make outdoor location determination more difficult.

Wireless Trondheim is the largest outdoor Wi-Fi deployment in Norway. LBS that utilize Wi-Fi RFID tags are believed to have a substantial business potential in this network. The current location-based solution in Wireless Trondheim has explicitly no support for determining location in outdoor environments. Nevertheless, testing is important in order to identify how well the Wi-Fi RFID technology currently perform in such environments. The results of such testing will determine what kind of services that can be supported, and the commercial potential for Wi-Fi RFID tags.

In this paper, the authors present results from the testing of Wi-Fi RFID tags in Wireless Trondheim. Two possible applications of Wi-Fi RFID tags within the citywide wireless network are also proposed. The current potential for these services are surveyed through three test scenarios. The test results point out several current limitations with the Wi-Fi RFID technology in outdoor environments.

The rest of this paper is structured as follows: Section II describes related work. In section III, two possible services, which utilize Wi-Fi RFID tags are proposed. Section IV presents three test scenarios. In Section V, the testing equipment and the location-based architecture in Wireless Trondheim are presented. Section VI describes the test evaluation and results. Finally, the concluding remarks are given in Section VII.

II. Related Work

Since 2004, a service utilizing Wi-Fi RFID tags to track children has been available in the theme park Legoland in Billund, Denmark. The theme park runs a 65 000 m^2 802.11 wireless network and utilizes 38 proprietary AeroScout location receivers to locate the tags. The location receivers supports Time Difference of Arrival (TDoA) and triangulation. A wristband with an AeroScout T2 Wi-Fi RFID tag is available for rent and can be attached to a child's arm. If the child is lost throughout the park, the parents can send a text message to the system, and get the location of their child. The system is capable of providing a positioning accuracy of 2 meters, with the tags transmitting every 8 seconds. The software solution is delivered by AeroScout and Kidspotter [9] [10] [11].

A test pilot similar to the Legoland system was also deployed in Yokohama, Japan in 2006. With participants like Nissan Motor Co. and NTT Communications, the main goal was to provide better safety for children on their way to and from school. In this deployment, the children used Wi-Fi RFID tags to alert parents and security personnel when in danger. Unlike the Legoland deployment, existing Cisco Wi-Fi access points were used instead of proprietary location receivers, together with AeroScout T2 tags and special AeroScout software [12] [13].

III. Proposed Services

A. City Bike Locator

There are currently 125 city bikes available for citizens and tourists in Trondheim [14]. Ten stations with electronically locked bike racks are deployed throughout the city center, and the majority of these stations are currently covered by Wireless Trondheim. Enabling location information about the bikes can be valuable for both the users and the providers of this service.

The City Bike Locator service offers an easier way of finding an available bike. In this service, location information is collected from Wi-Fi RFID tags fixed to the bikes. The Wi-Fi infrastructure is utilized to monitor the bike locations. Through a simple web interface, the user can locate the nearest available city bike by inputting his/her current location.

B. Find Your Friends

Social networking services are currently popular within the Internet communities. In such services, the users send messages to each other, comment each others photos and discuss upcoming events. The users also have the opportunity of manually inputting their current location or status information. However, it is possible to expand this type of service to include automatic location information with the use of Wi-Fi RFID tags attached to the users.

The Find Your Friends service utilizes location information collected from users carrying Wi-Fi RFID tags. The users can use the service to be notified about friends that currently are in the neighborhood. The location information can also be utilized to show status messages, telling whether the user is at home, at work or out in the city center.

IV. Testing Equipment

The Wi-Fi RFID tags used in the location tests in Wireless Trondheim were AeroScout T2 tags. This type of tag includes a 2.4GHz IEEE 802.11b transceiver for communication with the network and a low frequency, short-range 125kHz receiver, which can be utilized when programming the tag. The AeroScout T2 tag uses Layer 2 multicasts when communicating, and does not associate to the network infrastructure during operation. At a pre-configured beaconing interval, the tag transmits a 30-byte 802.11 data frame on up to three different channels. To avoid collisions in the network, the tag uses clear channel assessments before transmitting the multicast. The tag also contains a motion sensor and has optional features like temperature sensor and call button [15].

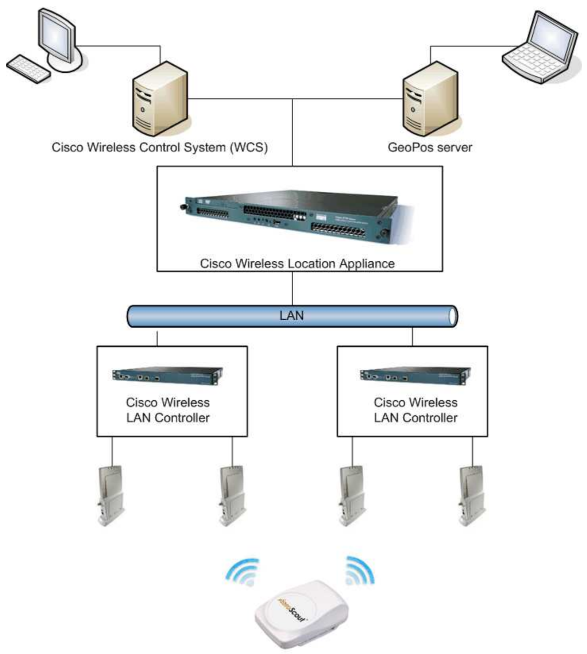

Fig. 1. The Wi-Fi RFID tag and the location-based architecture in Wireless Trondheim used in the tests. Based on sub figures from [2] and [16]

The Wireless Trondheim location-based infrastructure utilizes equipment from Cisco Systems, such as light-weight access points, access point controllers and a location server. Each access point that receives signals from the AeroScout T2 tag collects Received Signal Strength Indication (RSSI) information about the tag and aggregates this information to the corresponding access point controller using the Light Weight Access Point Protocol (LWAPP). The location server, the Cisco Wireless Location Appliance, periodically polls all the controllers for location information, using the Simple Network Management Protocol (SNMP) and computes the tag location based on the RSSI information. The Cisco Wireless Control System (WCS) can then be used to get a graphical representation of the tag location [7]. In addition to the WCS interface, the location server has a Simple Object Access Protocol (SOAP)/Extended Markup Language (XML) Application Programming Interface (API) that can be used by third party applications for LBS. In Wireless Trondheim, the Geographical Positioning Server (GeoPos) Web Service is a brokering service, which utilizes this API to get the tag location coordinates securely from the location server [17]. The communication between the AeroScout T2 tag and the Wireless Trondheim location-based architecture is illustrated in Fig. 1.

To get the real-life location coordinates, an additional Tom-Tom Global Positioning System (GPS) receiver was utilized during the testing. The tag location coordinates computed by the location server were collected from the GeoPos Web Service. Both sets of location coordinates were then plotted in the map-authoring software ArcMap [18]. Finally, the error distances between the two coordinate sets were computed in ArcMap and analyzed.

V. Test Scenarios

Three test scenarios were carried out in order to survey the performance of the tag and the location-based network solution. The test scenarios were carried out within the Wireless Trondheim coverage areas shown in Fig. 2.

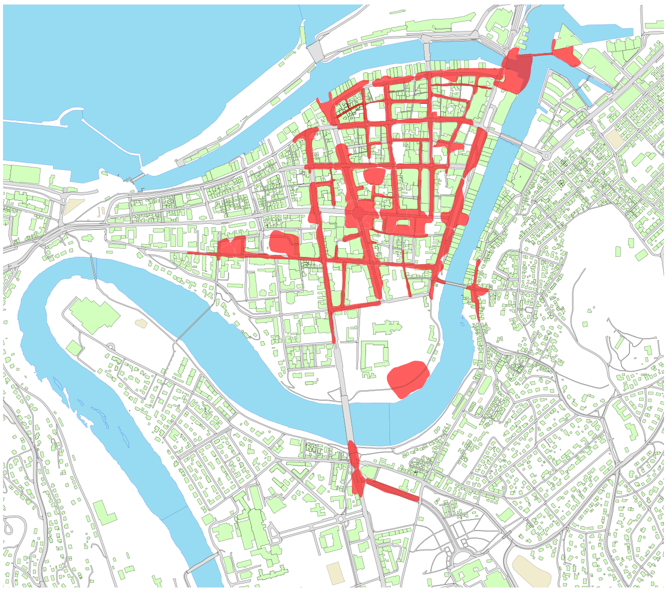

Fig. 2. The Wireless Trondheim coverage areas in the scale 1:10 000. Areas with at least 11 Mbps are shaded in the figure. The figure is obtained from Trådløse Trondheim AS.

In all the test scenarios, the tag was configured to transmit its multicast frame every 10 seconds, on channels 1, 6 and 11. The tag transmission power was set to the default value of +18 dBm. In the third scenario, an additional test was performed with the transmission power reduced to +15 dBm, which is equal to the transmission power of the Wi-Fi card in a regular laptop [19]. The tag message repetition interval was adjusted to 1, causing only a single multicast frame being sent with each transmission. The location server's polling interval was set to 30 seconds and the location smoothing algorithm was set to "Less smoothing". The new location is then given a three times higher value than the previous location in the location computation.

A. Static Location

The static location test scenario was carried out in order to examine the location accuracy when the Wi-Fi RFID tag is located at a static location for 10 minutes. The scenario was carried out in two separate areas, one covered by a single access point only and another with multiple access point coverage. This was done in order to examine how triangulation possibilities affect the location accuracy. At each of the two locations, three tests with 10 location measurements each were performed.

B. Dynamic Location

The purpose of the dynamic location test scenario was to see whether Wi-Fi RFID tag movements within a coverage area are detected by the location-based network solution. To what degree such movements affect the location accuracy was also observed. A single test were performed with 10 location measurements in an area covered by multiple access points.

C. Real-time Location

The goal with the real-time location test scenario was to identify whether the Wireless Trondheim deployment can support real-time services for tracking highly mobile items. In this test scenario, a bike was used to move the Wi-Fi RFID tag throughout the city center. At 12 different locations, a one minute stop was performed. The locations and the test route are depicted in Fig. 3.

Fig. 3. The real-time test route. The test was started and stopped at the location marked with "S". A one minute stop were performed at each of the numbered locations. Figure created using the Google Maps API [20].

The location computed by the location server was automatically requested from the GeoPos Web Service every second minute. The locations were then plotted in a map. The test was performed twice, using a tag transmission level of +18 dBm and +15 dBm respectively.

VI. Test Evaluation and Results

A. General Observations

A problem with delays in the computed locations were discovered when performing the test scenarios. This problem occurred when moving the Wi-Fi RFID tag between adjacent coverage areas. At the time of arrival in the new coverage area, the computed tag location remained in the previous coverage area for up to 15 minutes after the arrival. Consecutive messages sent by the tag every 10 seconds during these minutes were not reflected in the computed location, even though the access points in the new coverage should have received these messages. This problem greatly affect the location accuracy during movements throughout the wireless coverage areas.

B. Static Location

The results from the static location scenario show that the majority of the computed locations coincide with the location of the access point, when the area is covered by a single access point only. Thus, the computed error distances are approximately equal to the distance from the real-life tag location to the location of the access point. The tag was placed around 100 meters from the access point, and the results then show an average error distance of approximately 90 meters.

In the second area, up to four different access points reported RSSI information about the Wi-Fi RFID tag. The results then show that the location accuracy varies greatly within each test run and among the three test runs. The precision of the computed locations is therefore limited. Fig. 4 illustrates the variations in the computed location.

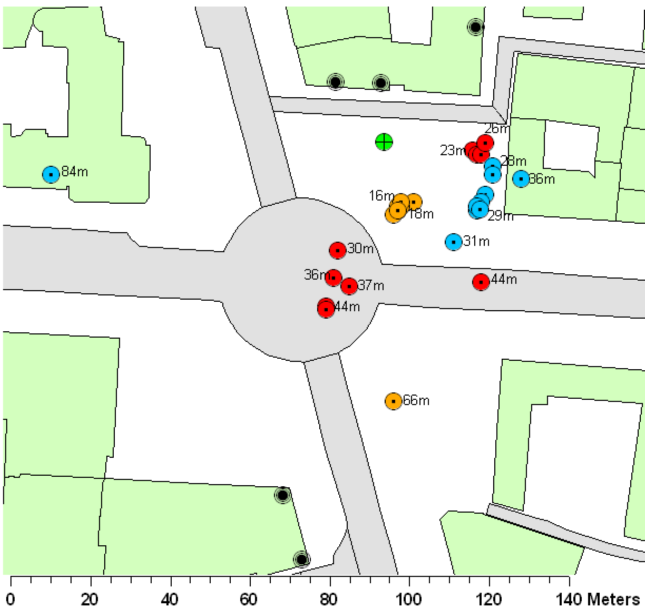

Fig. 4. The static location test results with multiple access points. There are considerable variations in the computed locations, which are marked with circles with a small dot in the center of the circle. Some of the error distances are also shown in the figure. The real-life location of the tag is indicated by a circle with a cross inside. Filled circles with two thinner surrounding circles denote access points.

The average error distance was computed to approximately 30 meters. By comparing these results to the results from the area with single access point coverage, it is possible to conclude that triangulation based on RSSI values provides a higher degree of location accuracy.

C. Dynamic Location

The results from the dynamic location scenario, indicate that movements over large distances in the coverage area are slowly reflected in the computed locations. The tag was entered in the coverage area from south and then moved by walking to the northwestern end of the area, where the first location was recorded. As depicted in Fig. 5, the first computed location is at the southern end, over 200 meters away from the real-life location.

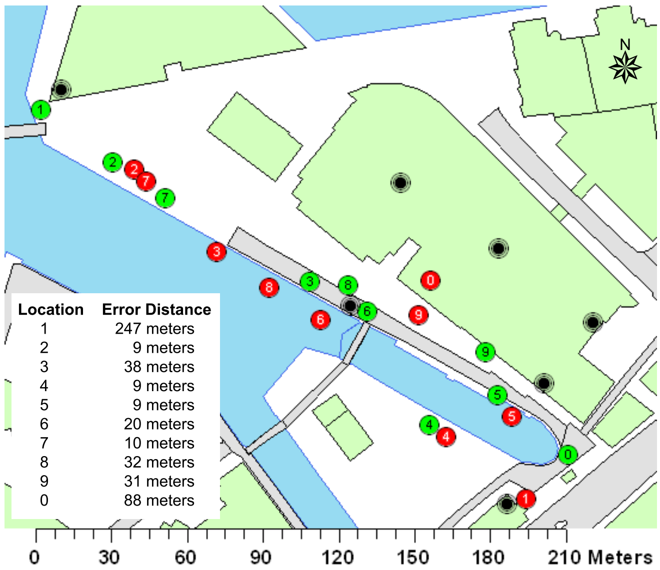

Fig. 5. The results of the dynamic location test with multiple access points. Circles with equal numbers illustrate the difference in the computed location and the real-life location. The real-life locations are marked with black numbers and the computed locations with white numbers. Filled circles with two thinner surrounding circles denote access points.

However, the computed location becomes more accurate after the next movement, where the accuracy is improved to 9 meters. The error distances then vary during the next movements. The total average error distance was computed to approximately 50 meters. The results also indicate that movements over shorter distances are more rapidly reflected in the computed location.

D. Real-time Location

The results from the real-time scenario illustrate how the problem with delays in the computed location occurs during movements between adjacent coverage areas, and how this problem affects the real-time performance of the LBS solution used in Wireless Trondheim. Movements across several areas with known wireless coverage are not reflected in the computed locations. The tag is located in only six main areas. The results are approximately equal with both the transmission power levels. However, the results indicate that the lowest transmission power level gives the best reflection of movement along the test route. Fig. 6 illustrates the results of the real-time scenario.

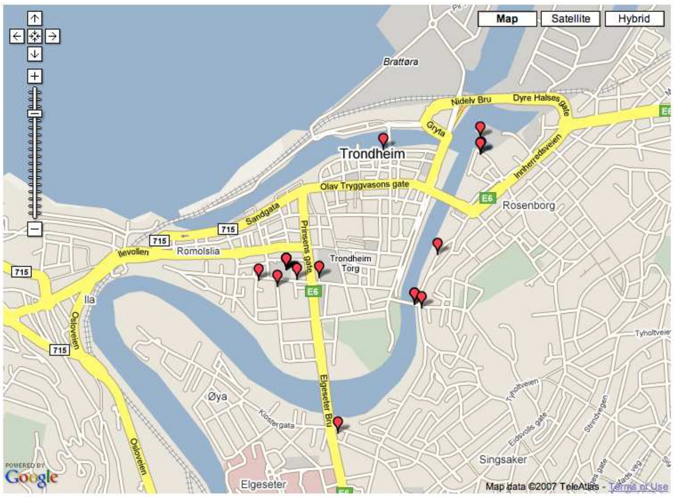

Fig. 6. The real-time test results with a tag transmission level of +15 dBm. Several of the locations in the city center are not reflected in the computed locations, even though they are within the Wireless Trondheim coverage areas. Figure created using the Google Maps API [20].

E. Possible Error Sources

Outdoor location support is not provided for the current software version of the Cisco location-based solution in Wireless Trondheim [21]. This is believed to be a major source for the location errors discovered in the test results. However, Cisco has promised an improved outdoor support in a software release in Q4 2007.

The access point density in Wireless Trondheim is lower than in a regular indoor Wi-Fi deployment. The access points also utilize external antennas and antennas with different characteristics regarding coverage. These two factors also affect the accuracy of the computed locations.

The unlicensed 2.4 GHz frequency band is heavily utilized both by 802.11 stations and other wireless equipment. Thus, interference is a known problem in this frequency band [22]. The interference can cause problems for the access points in the reception of 802.11 frames. The Wi-Fi RFID tags used in the tests were configured to send only one frame with every transmission. If there is interference on the channel during the transmission, the access point may not receive this frame. In such cases, the tag location will not be reported. Interference is believed to be a considerable error source to the test results.

The test results presented in this paper are based on a small number of measurements. Thus, the obtained results give indications on the performance of the Wi-Fi RFID tags and the location-based infrastructure rather than having statistically significance.

VII. Conclusions

The requirements to the performance of the Wi-Fi RFID technology differ among LBS. Hence, comprehensive testing is important when considering the commercial potential for Wi-Fi RFID tags in citywide wireless networks.

Although the test results presented in this paper point out considerable variations in the accuracy of the computed tag locations, and challenges related to delayed location information, LBS still have potential in citywide networks like Wireless Trondheim. The current location accuracy is considered to work well for several services. The service for finding your friends suggested in this paper is an example of a commercial service that could work with the current constraints. Real-time services with strict requirements to the location accuracy and services involving movement e.g. tracking assets are currently not supported by Wi-Fi RFID technology in outdoor environments like Wireless Trondheim. However, this may change as the technology matures and improvements are made in the location-based network solution.

References

[1] D. E. Brown, *RFID implementation*, ser. McGraw-Hill communications. New York: McGraw-Hill, 2007.
[2] (2007) The AeroScout, Inc. website. [Online]. Available: http://www.aeroscout.com/
[3] (2007) The Ekahau, Inc. website. [Online]. Available: http://www.ekahau.com/
[4] (2007) The PanGo, Inc. website. [Online]. Available: http://www.pango.com/
[5] (2007) The Radionor Communications AS website. [Online]. Available: http://www.radionor.no/
[6] “KangNam St. Mary’s Hospital,” Case Study, AeroScout, Inc., 2006.
[7] “Wi-Fi Location-Based Services - Design and Deployment Considerations,” Design Guide, Cisco Systems, Inc., 2006.
[8] “Evolution of Municipal Wireless Networks,” White Paper, Cisco Systems, Inc., november 2006.
[9] “Child tracking Application at Legoland,” Case Study, AeroScout, Inc., 2005.
[10] J. Strandbygaard, private communication, KidSpotter A/S, march 2007.
[11] J. Collins. (2004, april) Lost and Found in Legoland. Web Article. RFID Journal. [Online]. Available: http://www.rfidjournal.com/article/articleview/921/1/1/
[12] J. Hazan. (2007, january) A winning game of tag from Israeli startup. Web Article. ISRAEL21c.org. [Online]. Available: http://www.israel21c.org/
[13] C. Swedberg. (2005, december) RFID Watches Over School Kids in Japan. Web Article. RFID Journal. [Online]. Available: http://www.rfidjournal.com/article/articleview/2050/
[14] (2007) The Municipality of Trondheim website - City Bikes (Norwegian). [Online]. Available: http://www.trondheim.kommune.no/content.ap?thisId=1117615043
[15] “AeroScout T2 Tag data sheet,” AeroScout, Inc., San Mateo, CA, US.
[16] (2007) The Cisco Systems, Inc. website. [Online]. Available: http://www.cisco.com/
[17] (2007) The NTNU GeoPos website. [Online]. Available: http://dellgeopos.item.ntnu.no/
[18] (2007) The ESRI website - About ArcMap. [Online]. Available: http://www.esri.com/software/arcgis/about/arcmap.html
[19] (2007) Apple Computer, Inc. website - AirPort Express - Technical Specifications. [Online]. Available: http://support.apple.com/specs/airport/
[20] (2007) The Google Maps API website. [Online]. Available: http://www.google.com/apis/maps/
[21] J. C. Albesa, private communication, Cisco Systems, Inc., april 2007.
[22] N. Golmie, “Interference in the 2.4 GHz ISM Band: Challenges and Solutions,” White Paper, National Institute of Standards and Technology, june 2001.