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Locata Performance in the Presence of WiFi Interference: Test Results

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BIOGRAPHY

Faisal Ahmed Khan is currently a Ph.D. student at University of New South Wales (UNSW). His main area of research is the analysis of interference effects in positioning environments. He holds an M.Phil degree from UNSW and a B.E. (Electronics) degree from NED UET, Pakistan. He has also gained hands-on experience in the field of Satellite Communications at the Institute of Space Technology, Pakistan and the Pakistan Space and Upper Atmosphere Research Commission.

Chris Rizos is a graduate of the School of Surveying, UNSW, obtaining a Bachelor of Surveying in 1975, and a Ph.D. in 1980. Chris is currently Professor and Head of the School of Surveying & Spatial Information Systems, UNSW. Chris has been researching the technology and high precision applications of GPS since 1985, and has published over 300 journal and conference papers. He is a Fellow of the Australian Institute of Navigation and a Fellow of the International Association of Geodesy (IAG). He is currently the Vice President of the IAG and a member of the Governing Board of the International GNSS Service (IGS).

Andrew Dempster is Director of Research in the School of Surveying & Spatial Information Systems, UNSW. He led the team that developed Australia's first GPS receiver in the late 80s and has been involved with satellite navigation ever since. His current research interests are GNSS receiver design, GNSS signal processing, and new location technologies.

ABSTRACT

Classically difficult positioning environments have always called for some augmentation technology to assist the Global Positioning System (GPS). “Locata” offers augmentation, and even replacement, to GPS in such environments. However, like any other system relying on wireless technology, a Locata positioning network faces issues in the presence of RF interference (RFI). This problem magnifies due the fact that Locata operates in the licence-free 2.4GHz ISM band. WiFi devices operating in this band have been identified as the most likely potential interferer, due partially to their use of the whole ISM band. This paper evaluates the performance of Locata in the presence of WiFi interference. A comparison of Version 2 and Version 3 devices is presented. It is shown that significant improvement has been made in Version 3 for rejecting RFI. Test results presented in this paper give an insight into this situation. Also, Locata characteristics have been identified which can be exploited to mitigate RFI issues.

1. INTRODUCTION

GPS has been available for more than two decades, providing positioning solutions to outdoor applications including construction, surveying and mining. However, GPS starts to fail in delivering high accuracy solutions when operated in classically difficult positioning environments. This poor solution accuracy is mainly due to weak signal levels, multipath, RF interference, signal blockages and poor geometry situations. “Locata” is a technology that offers solutions to such shortcomings by providing augmentation, and even replacement, of GPS or other Global Navigation Satellite Systems (GNSS) in such situations. Locata’s positioning network (or “LocataNet”) is comprised of time-synchronized terrestrial transceivers (called “LocataLites”) operating in the 2.4GHz ISM band transmitting signals for positioning. Operation in the ISM band permits signal transmission at much higher power levels than for GPS, and eliminates any licence requirement. This makes the system feasible for deployment in any situation and environment. Nevertheless, operation in the ISM band incurs RF interference (RFI) from various other devices using the same frequency band. Interference originating from these devices can be divided into two categories: narrow-band and wide-band interferers. Narrow-band interferers include Bluetooth devices, cordless phones and harmonics

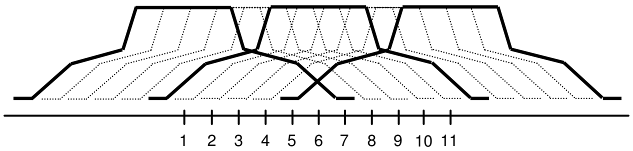

Figure 1 - Overlapping WiFi channels. Use of channel 1, 6 and 11 (shown as bold) is recommended for reducing overlap.

from out-of-band signals. The other category, wide-band interferes, mainly include microwave ovens and, as we examine here, WiFi devices.
In most of the environments where Locata operations are envisaged, such as on construction or surveying sites, indoor or urban canyon environments, the presence of WiFi devices is highly likely. These devices can transmit at any of the equally spaced 20 MHz wide channels. With a total of 11 channels, WiFi transmissions potentially cover the whole ISM band, as shown in Figure 1. In this paper we focus on identification of interference issues due to these WiFi devices. Test results, presented later in this paper, indicate that in the presence of interference it is possible that Locata may perform at a sub-optimal level. This could either result due to partial distortion of Locata's received signal or complete jamming of reception altogether. This complete jamming of the signal can be very crucial, as this may prohibit a receiver from listening to an interference-affected LocataLite's signal, resulting in possible deterioration of network geometry. These WiFi devices are capable of transmitting signals at different power levels, depending upon their location and the transmission data rate. It has been identified that WiFi signals transmitted at different data rates have different effects on Locata performance due to reasons explained later in section 2. This is also confirmed using test results.

Locata has recently released Version 3 devices. During the tests discussed in this paper it was identified that there has been a remarkable improvement in interference rejection in Version 3. It has also been determined that certain characteristics of a LocataNet, such as use of dual-frequency carriers, dual-antenna transmissions, TDMA-based operation and presence of multiple carrier tracking loops, can be exploited for further interference mitigation.

This paper is organized into six sections. After introducing the problem in the first section, in section 2 we present the system definitions associated interfering and interfered networks. Here, we also identify the parameters which we observe to determine the effects of different levels of received interference. Section 3 defines the test methodology, and the test results are presented and discussed in section 4. In section 5 we discuss the Locata characteristics which can be exploited to mitigate interference effects. Finally section 6 presents the concluding remarks.

2. SYSTEM SPECIFICATIONS AND COMPARISON

Locata, as mentioned above, employs CDMA-based time-synchronized LocataLites operating on dual-frequency carriers in the 2.4GHz ISM band. Each LocataLite can transmit through two different antennas, with each antenna transmitting at two different frequencies. This makes a total of four carriers being transmitted from a single LocataLite, each using a different PRN code at a 10MHz chipping rate. Transmission of carriers at two different frequencies and the use of two antennas allows exploitation of frequency and spatial diversity. Each LocataLite can be configured to transmit up to 200mW, in a pulsing manner to alleviate near-far issues. With this level of transmitted power, an operating range of around 4km can be expected. Different types of antennas, including right-hand circular polarized patch antennas and custom built ¼ wave antennas [1], have been tested and found to work well. Locata devices have FPGA-based modular architectures, which enhances system flexibility.

WiFi devices, using IEEE 802.11 b and g protocols, operate on any of the 11 channels covering the whole 2.4-2.5GHz ISM band spectrum. These are capable of transmitting at different data rates with EIRP levels exceeding 25dBm, with lower data rates being transmitted at higher power. Table 1 presents the typical power levels employed by WiFi devices to transmit at different data rates. It should be noted that these power levels are only indicative and vary from manufacturer to manufacturer. With these power levels, these devices can cover an area from about 40 metres (indoors) to 140 metres or more (outdoors).

Data Rate (Mbps)	Protocol	Transmit Power (dBm)
1 – 11	802.11b	19
6 – 24	802.11g	18
36	802.11g	17
48 – 54	802.11g	11-13

Table 1 – WiFi Transmit Powers at Different Data Rates for Netgear WG series router used for this work. Values are typical of most of the WiFi transmitters currently marketed.

Apart from the fact that data at different rates is transmitted at different power levels, channel loading also contributes to the amount of energy transmitted at different data rates to the channel. To understand this, consider the WiFi data format presented in Figure 2. The WiFi PLCP (Physical Layer Convergence Protocol) frame structure is given in Fig. 2a. This frame can be transmitted at any of the eight data rates. Here the durations of the Preamble and the Signal fields are data rate independent. For 802.11g, these are transmitted in 16μs and 4μs respectively [2]. The Signal field consists of a Rate sub-field, which sets the data rate at which the Data field is

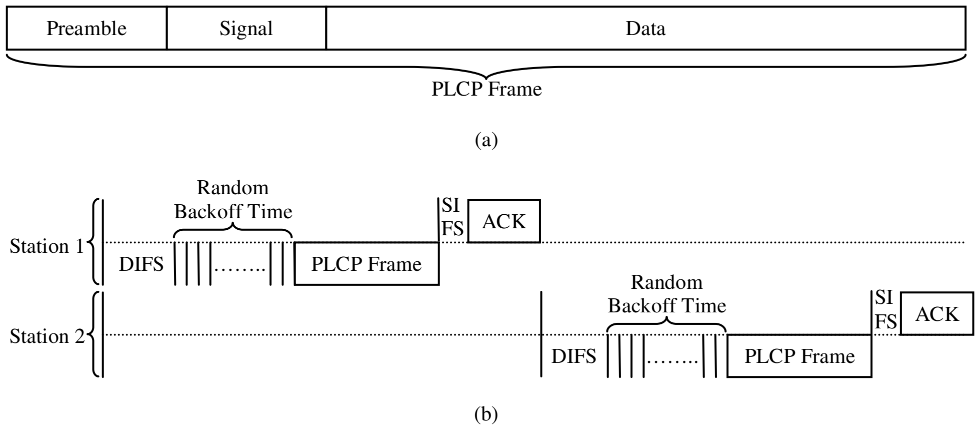

Figure 2(a) - WiFi PLCP data frame structure, (b) WiFi transmission cycle

transmitted. This scheme results in transmission of higher data rate frames in shorter durations. Fig. 2b shows the WiFi transmission cycle. Again, all the durations shown in Figure 2 are rate independent, except the Data and ACK field. In a WiFi transmission cycle, every station waits while the channel is busy. A detailed description of the WiFi transmission scheme can be found in [2]. To summarize, during DIFS, Random Backoff Time and SIFS, no station transmits any signal; these are only transmitted during PLCP Frame and ACK durations. It can be inferred from this discussion that the channel will be occupied for shorter durations when WiFi devices use higher data rates. That is, WiFi data transmissions at higher rates should produce less interference for LocataNet. This is also confirmed by the test results presented later in this paper.

Considering the specifications given above for the WiFi and Locata networks, the presence of inter-system interference becomes inevitable. It can be readily noted that the carriers from the two networks overlap each other and performance degradation can be expected when the devices from these two networks are located within the operating range of each other. Tests were conducted in order to observe the effects of WiFi-based interference on LocataNet performance and are detailed in the following section. The parameters selected for observing interference effects include carrier phase measurements and other performance indicators present in the raw data. Carrier phase measurements were the main observables because Locata mainly provides positioning solutions using these measurements. Any corruption of these measurements would also hamper the final solution accuracy.

3. TEST METHODOLOGY

Figure 3 shows the test setup adopted for determining the performance of Locata in the presence of WiFi generated interference. The LocataLite and rover receiver were connected via cables. This was done in order to avoid any undesirable interference signals and to maintain the controlled environment. Pathloss, which would be experienced in a real-world scenario, was simulated by introducing attenuation in the signal path. A splitter/combiner was used to tap into the WiFi connection so that WiFi signals can be combined with the Locata signals from the LocataLite and fed into the Locata rover receiver. These WiFi signals served as the interference signals. Initially the rover was made to operate in the absence of any interference. Observations at this stage served as a reference for the tests that follow.

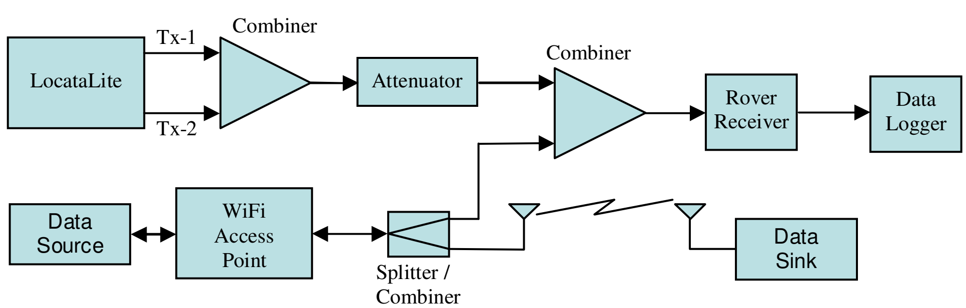

Figure 3 - Test setup for observing interference effects on Locata performance. All equipment is cabled together to avoid any undesirable interference and keep the test conditions under control.

Data was then transmitted from the data source to the data sink at different data rates, and raw data coming out of the rover receiver was recorded on a PC. Both Version 2 and Version 3 Locata devices were tested.

4. TEST RESULTS

Tests were carried out in the presence and absence of WiFi interference for both Version 2 and Version 3, as stated above. The following sub-sections detail the test results.

A. INTEGRATED CARRIER PHASE

Locata mainly provides a carrier phase solution, which makes Integrated Carrier Phase (ICP) measurements by the Locata rover receiver very critical. As the pseudoranges are calculated on the basis of these phase measurements, any error here will be directly reflected in the positioning solution. When Locata was made to operate in the vicinity of WiFi transmitters, ICP measurements started to get noisy and cycle slips were observed in these measurements. Figure 4 shows the standard deviation of the single-differenced ICP values, plotted against different data rates. Each of these data rates indicates different levels of interference with the lowest data rate having the highest potential of introducing interference. It can be noticed here that ICP measurements get noisier with a decrease in interfering

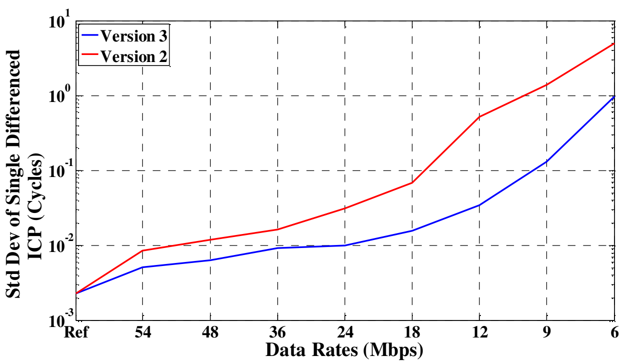

Figure 4 – Standard Deviation of Between-Carrier, Single-Differenced Integrated Carrier Phase.

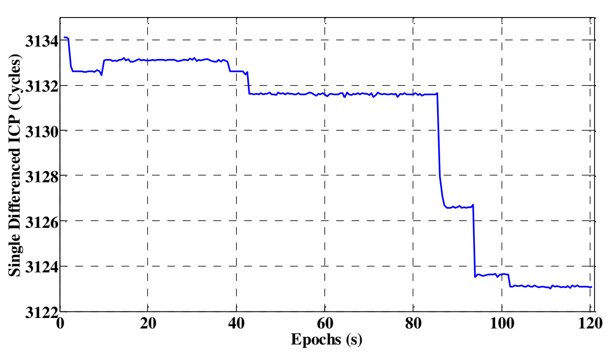

Figure 5 - Cycle Slips Occurring in Carrier Tracking Loop (CTL) in Version 3 in Presence of Interfering Signals Transmitted at 6 Mbps.

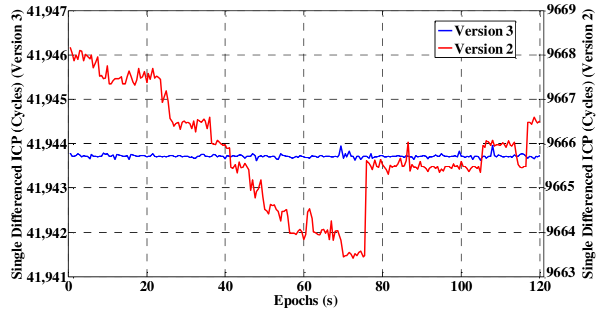

Figure 6 – Performance comparison, in presence of same levels of interference, for Version 2 and Version 3 Locata, in terms of cycle slips in ICP measurements.

signal's data rates. The situation gets worse as we move from higher data rates to lower ones, and eventually cycle slips can be observed in ICP measurements when the WiFi interfering signal is transmitted at 6Mbps. Using two co-frequency carriers transmitted from the same LocataLite, between-carrier single-differenced ICP values were calculated in order to remove any clock bias and observe cycle slips. Figure 5 shows this data, where frequent cycle slips in one of the Carrier Tracking Loops (CTL) in Version 3 can be observed. Version 2, on the other hand, was not able to remain in lock at these levels of interference. When both versions were tested in the presence of relatively low levels of interference, it was confirmed that Version 3 can avoid cycle slips better than Version 2, when exposed to the same level of interference. These tests were carried out when interfering data signals were transmitted at 9 Mbps, and the situation is depicted in Figure 6. Similar results were observed when interfering signals were transmitted at 12 and 18 Mbps. By comparing the performance of Locata Version 2 and Version 3 in Figure 4, it can readily be seen that Version 3 employs much improved interference rejection techniques compared to Version 2.

B. PERFORMANCE INDICATORS

A Locata rover receiver outputs signal-to-noise ratio (SNR) values as raw data. These values were recorded while the rover receiver performance degraded in the presence of an interfering signal being transmitted at different data rates. A plot of these values for both Versions 2 and 3 is given in Figure 7. Again, here the Ref. point shows the situation when the Locata receiver was operating in the absence of WiFi interference. Improvement in interference rejection in Version 3 is also evident from this plot. It can clearly be seen that Version 3 maintains higher SNR values than Version 2.

The other parameter chosen as an observable was a proprietary field (termed Prop6) that indicates the correlator performance. The description of this field is proprietary, however, it can be stated that higher numbers here indicate degraded performance. Values for this parameter are presented in Figure 8, which again presents

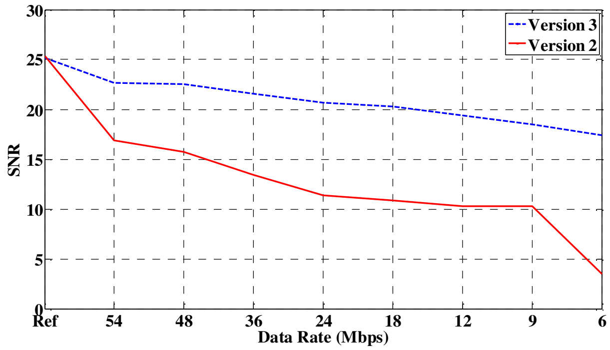

Figure 7 - Locata SNR in presence of Different Levels of Interference

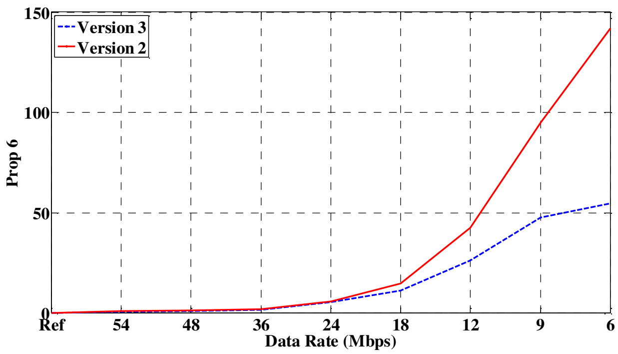

Figure 7 - Locata correlator performance in presence of different levels of interference

a comparison of Version 2 and Version 3. The correlator in a CDMA receiver plays a critical role, and the performance of whole receiver functionality depends on this block. It can be noticed here that although Version 2 was not performing well in the presence of higher levels of interference, Version 3 provides much improved performance.

5. INTERFERENCE MITIGATION

From the results presented above, it can be noted that although improvements have been introduced in Version 3 for rejecting interference, Locata can still suffer due to the presence of some interference. However, we can identify various LocataNet characteristics that can be exploited for further mitigation of the interference.

A. DUAL-FREQUENCY/DUAL-ANTENNA SYSTEM

Interference mitigation can be introduced by exploiting frequency and/or spatial diversity. It is possible that we can use one of the carrier frequencies for measurements, while the other is affected by received RF interference. Also, the dual-antenna system can allow us, in principle, to choose between the interfered and non-interfered signal.

B. TDMA NATURE

Locata employs Time Division Multiple Access (TDMA) schemes, allocating time slots to individual LocataLites. The chances of interference can be reduced by restricting LocataLites to transmit in particular time slots. A scheme using this concept has already been described [4].

C. PRESENCE OF MULTIPLE CTL

Locata tracks four carriers from each LocataLite on two different frequencies. This can be exploited by the use of loop aiding. Loop aiding can help by simultaneously handling high dynamics and mitigation of RF interference. Work on this concept is still progressing.

6. CONCLUDING REMARKS

In this paper we discussed the Locata performance in the presence of WiFi networks. Test results were presented and a comparison of the performance of the recently released Locata Version 3 was made with the previous version. These tests evaluated Locata performance in terms of parameters including carrier phase measurements and other performance indicators. It was identified that Locata Version 3 includes much enhanced interference rejection characteristics relative to previous versions. It was also identified that there is still room for improvement in terms of interference rejection. LocataNet characteristics were identified which can be exploited to mitigate received interference. It is proposed that loop aiding can robustly be used for this purpose.

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