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Novel Time-Sharing Scheme for Virtual Elimination of Locata-WiFi Interference Effects

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BIOGRAPHY

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Andrew Dempster is Director of Research in the School of Surveying and Spatial Information Systems at the University of New South Wales. 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

Solution accuracy of global navigation satellite systems (GNSS) is often compromised by the satellite-user geometry, weak signal levels and system outages. Locata Corporation's positioning technology potentially bridges such gaps in availability, providing cm-level accuracy in challenging positioning environments. A Locata network consists of time-synchronized terrestrial transceivers (called LocataLites) operating in the 2.4 GHz Industrial, Scientific and Medical (ISM) band, transmitting signals appropriate for positioning. However, operation in a license-free band suffers from RF interference from various other communications and radio systems using the same portion of frequency spectrum. Among various other systems, WiFi devices are of special concern. Although there has been a significant improvement in Locata's immunity to WiFi jamming in the latest hardware release, interference from WiFi may still hamper Locata's performance. This paper proposes a novel scheme to virtually eliminate WiFi interference to Locata. This scheme exploits the underlying Time Division Multiple Access (TDMA)-based functionality of both systems to force them to operate in a pseudo-synchronized manner, without any direct connectivity between systems. A new signal is proposed to be added to the Locata system, which will dictate the level of inter-system interference. Controlling this inter-system interference will not only offer control over the levels of solution accuracy from Locata but also over achieved data message throughput for the WiFi network. The advantage of this scheme is that it can be implemented for avoiding interference issues between WiFi and any other Software Defined Radio (SDR)/FPGA based communications system operating in the same band.

1. INTRODUCTION

GNSS, and especially the Global Positioning System (GPS), has long been used for determining position, velocity, time and attitude. Many current applications of GNSS require high accuracy and reliability. Nevertheless, the level of accuracy achieved depends upon the constellation-user geometry, available signal quality and extent of system outage. These issues are addressed by Locata Corp's positioning technology. This positioning system comprises a network of dual-frequency time-synchronized ISM band transceivers, transmitting ranging signals appropriate for positioning. In contrast to GNSS systems, where time-of-observation is the main influence on user system geometry due to motion of the satellites, system geometry can be relatively fixed in a Locata network. The Locata system employs both frequency and spatial diversity to mitigate multipath and interference. Still, like any other wireless communications system, Locata can suffer degraded solution quality due to received signal interference. This interference can emanate from not only in-band transmitters, but harmonics from out-of-band systems can also pose serious threats. WiFi, which also operates in the same 80 MHz wide ISM band as Locata, and essentially covers the whole band, has been identified as a potential interferer to Locata network signals. Co-existence of Locata and WiFi networks is highly likely to occur. For instance, currently Locata networks are being deployed in open-pit mines [1], where WiFi-based networks are also in use for communications. Also, it is proposed that in the near future Locata will be used for indoor positioning on either a fixed or ad-hoc basis, where the presence of WiFi networks would be expected. Significant improvement in system design has already been made in avoiding solution degradation for Locata in the presence of WiFi interference [2]. However, a WiFi transmitter can still disrupt Locata operation. On the other hand, Locata will also interfere with the WiFi network(s), thereby reducing its(their) data throughput.

The most effective way to virtually eliminate all interference issues requires one system to stop its transmissions while the other system is accessing the channel. Locata works on a TDMA-based scheme, allocating slots ('Locata slots') to each LocataLite, for their transmission. Similarly, WiFi devices also use time slots to transfer their packets. If overlapping of these time-slots can be avoided, inter-system interference between WiFi and Locata can virtually be eliminated.

One theoretical way to achieve this is by synchronizing both systems to avoid allocated time-slot overlapping. Another pragmatic approach is to exploit inherent characteristics of both Locata and WiFi to make them operate in a time-synchronized manner. The scheme proposed in this paper adopts the second approach. This approach is selected because it will not require any changes to the WiFi network, which is not feasible anyway.

In section 2 of this paper the authors describe the characteristics of Locata and WiFi. Section 3 details the proposed scheme, and gives the channel access timing-diagram and scheme justification. This is followed, in section 4, by an analysis of Locata performance and WiFi data message throughput via simulation studies in the presence and absence of inter-system interference. This section also suggests a trade-off for the performance of Locata and WiFi networks. Finally, section 5 concludes the paper.

2. NETWORK CHARACTERISTICS

Locata, as mentioned above, employs a TDMA-based scheme and operates within a Master-Slave architecture. Time-synchronization is achieved by synchronizing all slave LocataLites to a master LocataLite's Navigation signal. This requires all LocataLites, except the master, to be equipped with a receiver for listening to the synchronizing signal. This makes LocataLites, and rover receivers, vulnerable to RFI. This TDMA-based scheme is employed to overcome multi-user interference due to the near-far effect. Initially the master is allowed to transmit at the beginning of each transmission cycle. All slave LocataLites listen to these signals to achieve synchronization. Then each LocataLite transmits its signals in its allocated Locata slot. Individual LocataLites are allowed to transmit in more than one consecutive slot. This slot allocation can be set at the time of network initialization. In the next section it is shown that this TDMA-based transmission scheme can be modified to avoid WiFi interference.

WiFi devices use IEEE 802.11 a, b and g protocols, based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), in order to avoid frame corruption. These require every node to, either virtually or physically, 'sense' the channel before starting its transmission. For physical sensing, Clear Channel Assessment is performed to determine if any other WiFi signal is already using the channel. Virtual sensing is performed by decoding the 'duration' field present in frames currently being transmitted on the channel. This field indicates the amount of time required for the transmission of that particular frame. Reading this field, every node sets an internal counter (Network Allocation Vector – NAV), which counts down for the indicated time, before that node tries to access the channel. The 'duration' field indicates time in microseconds and can carry any value up to 32767, irrespective of the actual duration of the packet that contains this field. If exploited, this virtual carrier sensing mechanism makes these protocols vulnerable to Denial of Service (DoS) attacks. It has been identified that if WiFi packets, with appropriate values in the 'duration' field, are periodically injected into the channel, any WiFi network can be silenced for the desired amount of time. For example, if an ACK packet with 32000 value in the 'duration' field is injected at a frequency of 32 packets/sec, it will prevent all the listening WiFi devices from accessing the channel for any desired amount of time (for details, the reader is advised to consult [3], [4]).

3. PROPOSED SCHEME

The above characteristics of Locata and WiFi networks enable a time-sharing scheme for implementing time-synchronous operation of both systems to be developed. 802.11's virtual carrier sensing capability has already been mentioned as an inherent vulnerability. In the proposed scheme this vulnerability can be exploited to virtually eliminate inter-system interference and enable inter-operability. Figure 1 shows the timing diagram of the proposed scheme.

In a Locata network, each LocataLite transmits during only allocated Locata time-slots. In the proposed time-sharing scheme it is proposed that the available time-slots in a single Locata transmission cycle be divided between Locata and WiFi. Implementation requires every LocataLite to transmit a probe, before transmitting its own data. This probe will be a WiFi-type packet defining a duration long enough to cover time for Locatalite's own packet transmission and some

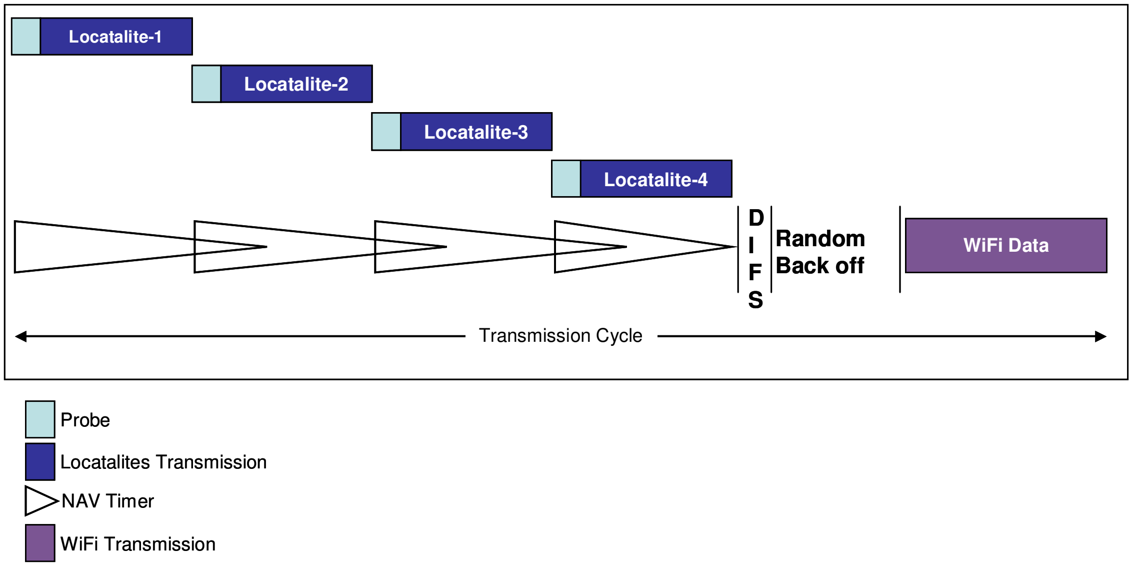

Figure 1. Timing Diagram

additional time. This additional time will be used by the next LocataLite to transmit its probe. As a response to this probe, all WiFi devices within the coverage area would refrain from accessing the channel, re-setting their NAV according to the duration defined in the probe. This would prevent WiFi devices from transmitting while their NAV counter counts down to zero. Consecutive probes will keep resetting the NAV, until all LocataLites transmit in their allocated slots. When all Locata slots allocated to LocataLites are elapsed, no more probes would be sent until the start of the next transmission cycle, leaving the NAV counter to reach zero value. Once the NAV counter reaches zero, a WiFi device will wait for Distributed Coordination Function Inter-frame Space (DIFS) and some random amount of time (random back-off), as defined by the 802.11 protocol. This can be followed by data transmission by the eligible WiFi device, in a Locata-interference-free environment, until the start of the next Locata transmission cycle.

In the currently implemented scheme, Locata's rover receiver listens to a particular LocataLite during the slot allocated to that LocataLite. Given the FPGA based nature of Locata devices, it is possible to program the rover not to listen to anything while the probe is being transmitted. This would avoid any possible interference from the probing signal to the rover's normal operation. The proposed scheme does not require any significant change in rover functionality. It will only turn on its receiver while Locata signals are being transmitted and will not listen to anything while the probe is being transmitted or when WiFi is allowed to use the channel.

Considering that it is possible for a single probe to silence WiFi for the complete Locata transmission cycle, an alternate solution could be that only one LocataLite (the master LocataLite, for instance) transmits a probe. This is possible, as each probe can silence WiFi for durations of more than 32ms. This time period is more than enough for one Locata transmission cycle. However, there is a catch to this solution. There could be a situation where an interfering WiFi device is not in the coverage area of the master LocataLite. In this case, that device will not be able to listen to the probe transmitted by the master LocataLite, and will keep on transmitting its signals. In the proposed scheme each LocataLite transmits the probe, accessing WiFi devices located anywhere in the Locata network's coverage area.

4. IMPLEMENTATION OUTCOMES

Experiments and simulations were performed to determine how Locata and WiFi performance are affected in an implementation of the proposed scheme.

A. Locata Performance Improvement

Locata performance was experimentally evaluated in the presence and absence of WiFi interference. It was assumed that injection of probing signals would prevent WiFi nodes from transmitting any interfering packets. This has experimentally been demonstrated in [4]. A Locata network of four LocataLites was set up in an urban-canyon environment. A rover receiver was allowed to acquire signals from LocataLites before any interference was introduced. Netgear's WG102 WiFi Access Point was used as an interference source and was placed at a distance of 10 metres from the rover. The rover output was observed in the presence and absence of WiFi interference.

The raw data, output by the rover, provides the number of low-correlator-output-events for each observation interval, i.e. the number of times per observation interval the correlator output was unable to meet the pre-set threshold. This also

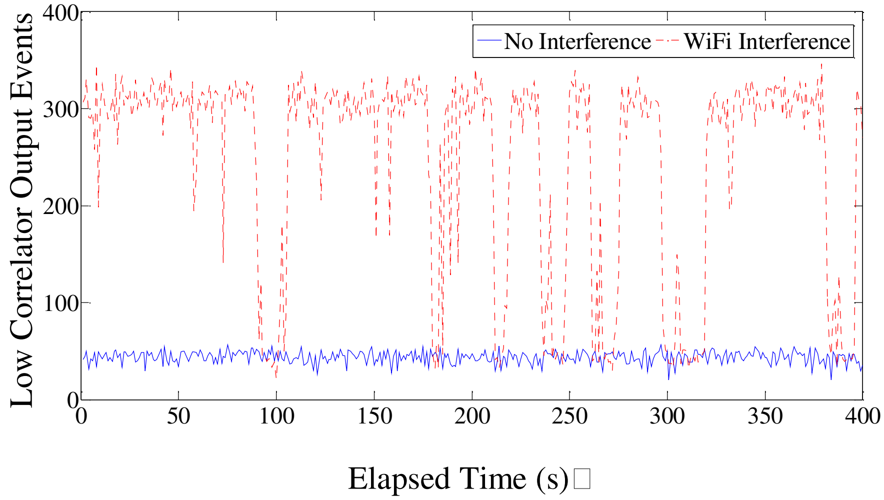

Figure 2. Number of Low-Correlator-Output-Power-Events in Presence of WiFi Interference

indicates the presence of interference, which was high enough to potentially keep correlator output below the threshold. This was chosen as the variable of interest for these experiments.
Figure 2 shows the low-correlator-output events, out of 500 total correlator outputs per observation interval of 0.5 sec each, in the presence and absence of WiFi interference. As Locata and WiFi both share the same portion of the ISM band, inter-system interference is inevitable. This can be observed in Figure 2, where a total of 800 observation intervals spanning a time period of 400 seconds are shown. It can be seen that correlator output was unable to meet the threshold for more than 50% of the total observed time, in the presence of interference. It is interesting to note that during this 50% time, there were at least 300 low-correlator-output events, out of a total of 500, during each observation interval.

After removal of interference, it was observed that these low-correlator-output events reduced from 300 to 50 for each observation interval. This value of 50 occurred due to some non-WiFi interference. In a perfectly clean environment, this value is expected to go down to zero. This shows the level of improvement in Locata performance that could be achieved by implementing the proposed scheme.

B. WiFi Performance Evaluation

In order to determine WiFi performance after implementation of the proposed scheme, WiFi throughput was simulated. The same approach was followed as was defined in [5] for throughput calculation. A WiFi network of three nodes was considered, each transmitting at a maximum data rate of 54 Mbps. Figure 3 shows the simulation results (dashed line) depicting different WiFi throughput values for different numbers of allocated Locata slots out of a total available sots. It should be noted that the highest throughput that can be achieved (28.45 Mbps) is much less than the claimed 54 Mbps, even when the WiFi network operates in the absence of Locata interference (denoted as Ref in Figure 3). This is due to protocol-based overheads and channel impairments. After implementation of this scheme, this throughput is predicted to reduce, depending upon the number of allocated Locata slots to the WiFi network, as shown by the simulation results in Figure 3. This is an important trade-off considering the decrease in the WiFi network's throughput. However, it needs to be noted that WiFi would still experience a considerable decrease in throughput while its data packets are being corrupted by Locata-induced interference.

C. Effect of Slot Allocations on Locata and WiFi Performance

It was observed in the previous section that altering the number of Locata slots allocated to WiFi could control the WiFi throughput. A larger number of allocated Locata slots to WiFi will lead to improved data throughput. Nevertheless, this will leave fewer Locata slots to be allocated to each individual LocataLite, which could result in sub-optimal performance. This suggests a trade-off between Locata's performance and WiFi's achieved data throughput, depending upon the allocated Locata slots to each network. To study this trade-off an experiment was performed, which recorded mean values of

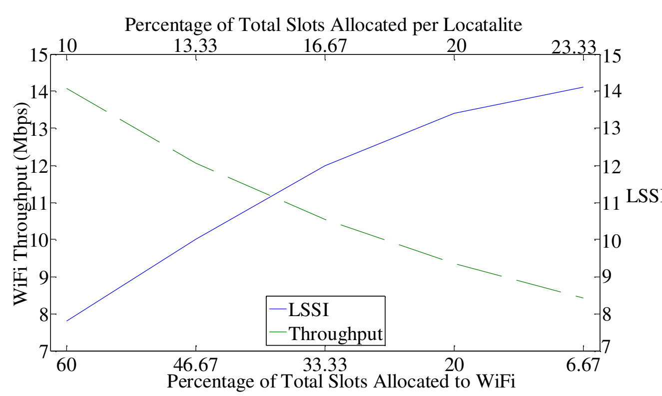

Figure 3. Effect of Allocated Slots on WiFi Throughput (left) and Locata Signal Strength Indicator (LSSI) (right)

Locata Signal Strength Indicator (LSSI) for a different number of allocated slots per LocataLite. This experiment considered a network of four LocataLites. A minimum of 10% of the total available slots is recommended to be allocated to each LocataLite. This permits a maximum of 10 LocataLites to be accommodated in a single transmission cycle. In order to increase the number of allocated slots per LocataLite, the number of LocataLites needs to be reduced. When the proposed scheme is implemented, these slots need to accommodate WiFi network devices in addition to LocataLites. Slot allocation considered for this experiment is given in Table 1. Recorded LSSI values were plotted against number of allocated slots. This graph was overlaid on a graph of WiFi throughput plotted against number of slots allocated to the WiFi network, to study the aforementioned trade-off. These graphs are shown in Figure 3. It is suggested that in order to increase throughput of the WiFi network, either fewer LocataLites should be used or the number of slots allocated to each LocataLite needs to be reduced. In the first option, network geometry and available signal quality at the rover may be affected. The latter option may lead to sub-optimal tracking performance for individual LocataLites. This is indicated by the solid line in Figure 3, which shows the LSSI increasing when more slots are allocated per LocataLite. Figure 3 presents an insight into the stated trade-off. An appropriate distribution of slots between Locata and WiFi networks can be suggested considering the levels of acceptable LSSI and WiFi throughput. For instance, allocating 66.67% of the total slots to a network of 4 LocataLites (i.e. 16.67% slots allocated per LocataLite) and remaining 33.33% slots to the WiFi network, a LSSI value of 12 for Locata and a throughput of 10.6 Mbps for the WiFi network can be achieved.

Slots per LocataLite	**Total Slots Used by Locata Network**	**Slots Used by WiFi Network**
10	40	60
13.33	53.33	46.67
16.66	66.67	33.33
20	80	20
23.33	93.33	6.67

Table 1. Slot Distribution Between Locata And Wifi Networks (All Values Expressed As A Percentage Of Total Available Slots In A Single Transmission Cycle)

5. CONCLUDING REMARKS

The proposed time-sharing scheme described in this paper offers inter-system operability with highly reduced inter-system interference. This is achieved by reducing the chances of overlapping of WiFi and Locata packets, at the expense of the transmission of an extra probing signal. The FPGA based design of Locata makes the introduction of this new signal practicable. Experimental results were presented that confirm the level of improvement that can be achieved for Locata. In addition, WiFi data throughput was predicted using simulation results. A trade-off is suggested between WiFi and Locata performance, which if not considered carefully, may lead to sub-optimal performance of either of the networks. This trade-off can easily be handled by the proposed signal (probe). If carefully implemented, the introduction of this new signal can virtually eliminate inter-system interference.

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REFERENCES

[1] J. Barnes, J. Lamance, B. Lilly, I. Rogers, M. Nix, A. Balls, "An Integrated Locata & Leica Geosystems Positioning System for Open-cut Mining Applications", ION GNSSS, Fort Worth, TX, USA, 25-28 September 2007.

[2] F.A. Khan, A.G. Dempster, C. Rizos, "Locata-based Positioning in the Presence of WiFi Interference: Test Results", to be presented at ION GNSS 2008, Savannah, Georgia, USA, 16-19 September 2008.

[3] Wullems, K. Tham, J. Smith, M. Looi, "A Trivial Denial of Service Attack on IEEE 802.11 Direct Sequence Spread Spectrum Wireless LANs", Wireless Telecommunications Symposium, California, USA, May 14-15, 2004, pages 129- 136.

[4] B. Chen, V. Muthukkumarasamy, "Denial of service attacks against 802.11 DCF", Proceedings of the IADIS International Conference: Applied Computing, San Sebastian, Spain, 25-28 February 2006.

[5] L. Wijesinha, Y. Song, M. Krishnan, V. Mathur, J. Ahn, V. Shyamasundar, "Throughput Measurement for UDP Traffic in an IEEE 802.11g WLAN", Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing, Towson, USA, 23 – 25 May, 2005, pages 220 – 225.