A WLAN Concept for Data Acquisition from Multiple Target Vehicles

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ABSTRACT

Tests for missile defense systems are very complex, and present challenging issues for the extraction of target lethality data. Future tests will involve the use of multiple interceptors and targets with some of these assets following over-the-horizon (OTH) trajectories. The use of wireless local area network (WLAN) technologies for the acquisition of test data offers a novel approach to manage data bandwidths and link margins over-the-air (OTA) as functions of time and asset. Notional test scenarios are examined for the suitability of WLAN technologies to missile defense intercept testing.

KEY WORDS

Wireless Local Area Network, IEEE802.11, Telemetry, Target Vehicles

INTRODUCTION

The U.S. Army's Yuma Proving Ground (YPG) has used COTS-based (commercial-off-the-shelf) 802.11b WLAN devices for data acquisition for several years (Ref 1). The existing YPG WLAN is currently configured using standard Ethernet Bridging and Wireless Ethernet Access Point/Client operations with 6 units providing a stationary backbone to provide coverage across the 100 km East-to-West expanse of the test center. One of the wireless sites is tied to the fiber optical network backbone that services all of YPG's computer systems. This network connection transfers all test data collected from the multiple wireless sources to wired data management systems. A computer architecture using "messaging" protocols also exists at YPG (called the Integrated Test Management Facility or ITMF) that re-orders and re-assembles data packets into organized files that can be accessed by test users or returned to the unit under test as needed (a metrological message for example). This WLAN has transferred test data from static and slow moving platforms under test. The impact of Doppler and Doppler rate on the 802.11b WLAN was examined analytically (Ref 2). Given the inherent frequency tolerance of 802.11b transceivers, Doppler effects are not expected to be important. Hand-over issues are a separate matter and will be addressed via analysis and flight test.

WLAN ISSUES TO BE CONSIDERED

There are many issues in the use of WLAN technologies that must be considered. Some of these are similar or related to standard telemetry, while some are not. A partial list of issues is:

1. Sufficient link margins for accurate data transfer
2. Doppler and hand-over effects
3. Multi-band antennas and power amplifiers
4. Noise problems due to uplink power levels
5. Amount of data to be transferred
6. Delay time in air between nodes
7. Network scalability for various data rates and the number of nodes
8. Over-the-air (OTA) re-addressing of data rates

9. Protocols for sending data
10. Buffering of data once it is "in the network"
11. Encryption of data and/or node addresses

This paper will address some of these issues. One of the basic features of the 802.11 architectures is that message traffic across the network can be prescribed as a function of time. This is not the case for standard point-to-point telemetry, since data pipes must be established in highly dedicated fashions, thus overwhelming the available spectrum. In order to understand how a WLAN approach might mitigate this problem, the issues of physical layer, data rates, and the number of nodes must be considered.

The 802.11 physical layers are very different, not only in transmission frequency (Instrumentation, Scientific, and Medical (ISM) band from 2.400 - 2.462 GHz for the "b" standard versus Unlicensed National Information Structure (U-NII) bands from 5.150 – 5.825 GHz for the "a") but also in the spreading techniques. 802.11b typically is implemented with direct sequence spread spectrum (DSSS) with data rates of 11, 5.5, 2, and 1 Mbps that use different modulation schemes. 802.11a is implemented with orthogonal frequency division multiplexing (OFDM) at data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbps. 802.11a also achieves these data rates by using different modulation techniques. Both standards employ similar networking architectures in that the media access control (MAC) implementations are the same. This allows for dual mode physical layers without conflicting networking standards.

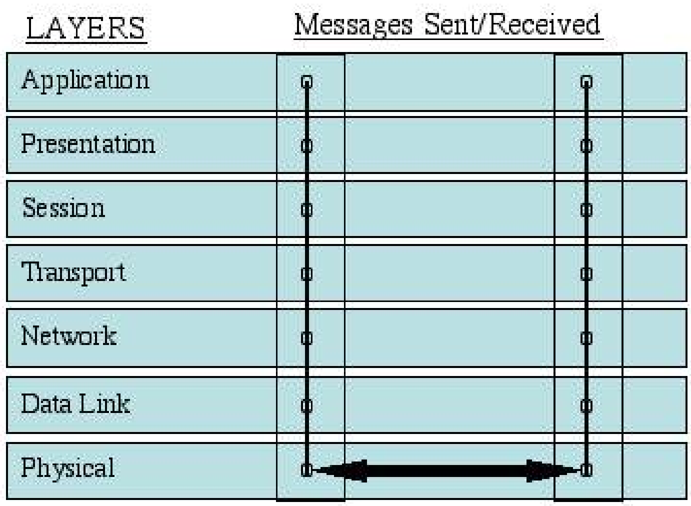
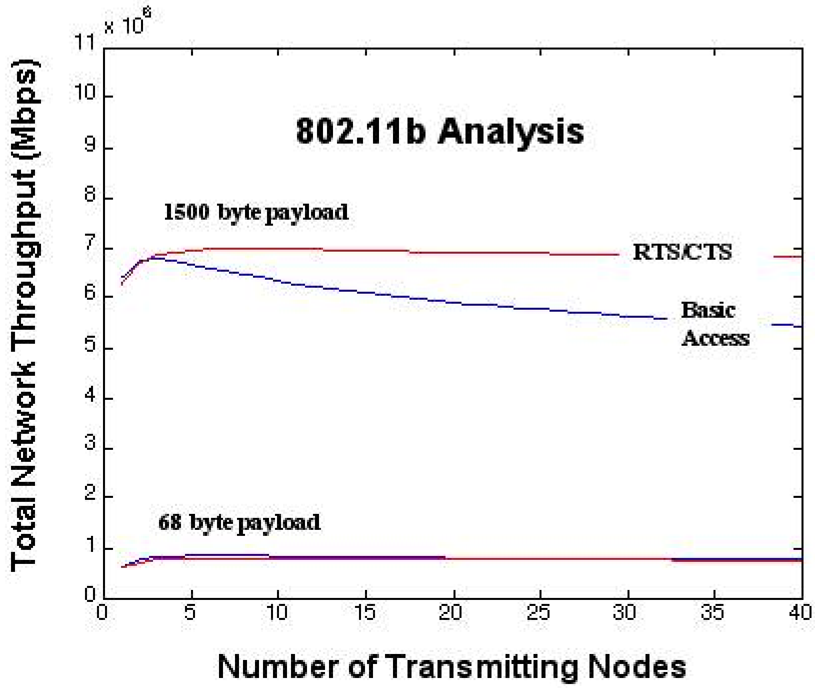


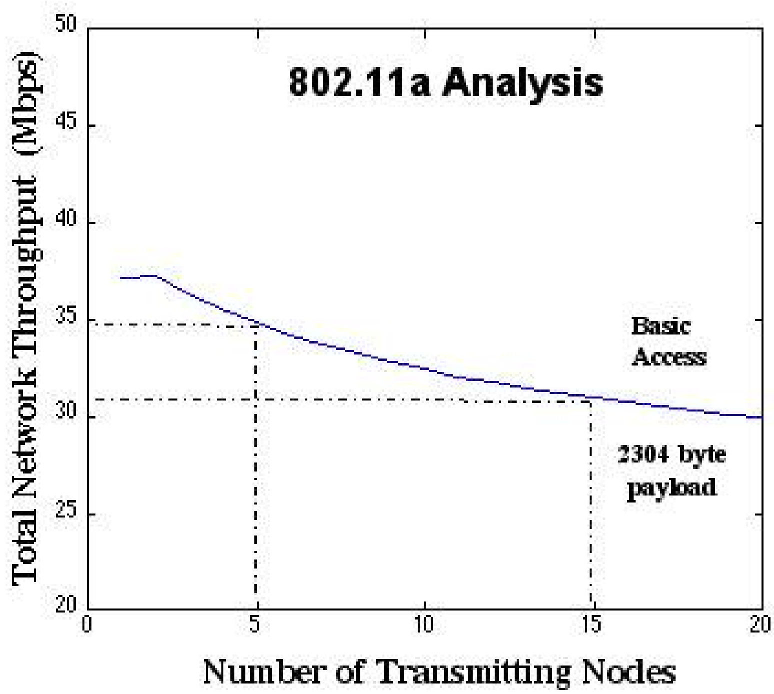
Figure 1. The Open Systems Interconnection 7-Layer Reference Model.

Data transfer via a network (wired or wireless) is highly nonlinear. Figure 1 depicts the Open Systems Interconnection 7-Layer (OSI-7) reference model. Data transfer using this model is highly nonlinear since a message entering the top of the stack is appended by header information and passed to the next layer. This process continues at each layer. The physical layer connection between the two users (or nodes) is shown with a double-headed arrow as a reminder that the traffic is truly 2-way. Consider some simple examples for network throughput, which will depend upon the transmission protocol (basic access or request-to-send/clear-to-send (RTS/CTS)), the payload size, and the number of transmitting nodes.

The amount of actual data (the payload) handled by the network is governed nonlinearly by the size of the payload. Figure 2a shows the effect of payload size on network performance for two transmission protocols. A small payload yields very inefficient throughput. Since the "a" and "b" MACs are the same, average network throughputs are similar with respect to the number of nodes and scaled by the respective maximum throughput (Figure 2b) for each standard.



Figures 2a. Network Scaling Issues for 802.11b



Figures 2b. Network Scaling Issues for 802.11a.

Interesting concepts spring from Figure 2b when one considers that a single channel in the U-NII band can support a nominal throughput of 30-35 Mbps for 5-15 nodes (see the dashed lines). A pictorial representation of the U-NII bands is presented in Figure 3. Some of these frequencies overlap with traditional C-band frequencies used by the T&E community for tracking radars. In fact, the upper most U-NII band directly conflicts with FPS-16 radars used at the Pacific Missile Range Facility. The "non-overlapping" channels are shaded (there are 3 in the lower and middle bands and there are 2 in the upper band). Combining the concepts from Figures 2b and 3, then 3 channels could support 15 to 45 nodes with a combined throughput approaching 100 Mbps without conflicting with the radars. For the case of 802.11b (Figure 2a), 3 non-overlapping channels could nominally support 20 nodes with a throughput of 20 Mbps across 50 MHz of the spectrum. These throughputs are not more efficient than a standard telemetry system; a WLAN approach cannot invent spectrum. The WLAN concept is to dynamically allocate the spectrum in time.

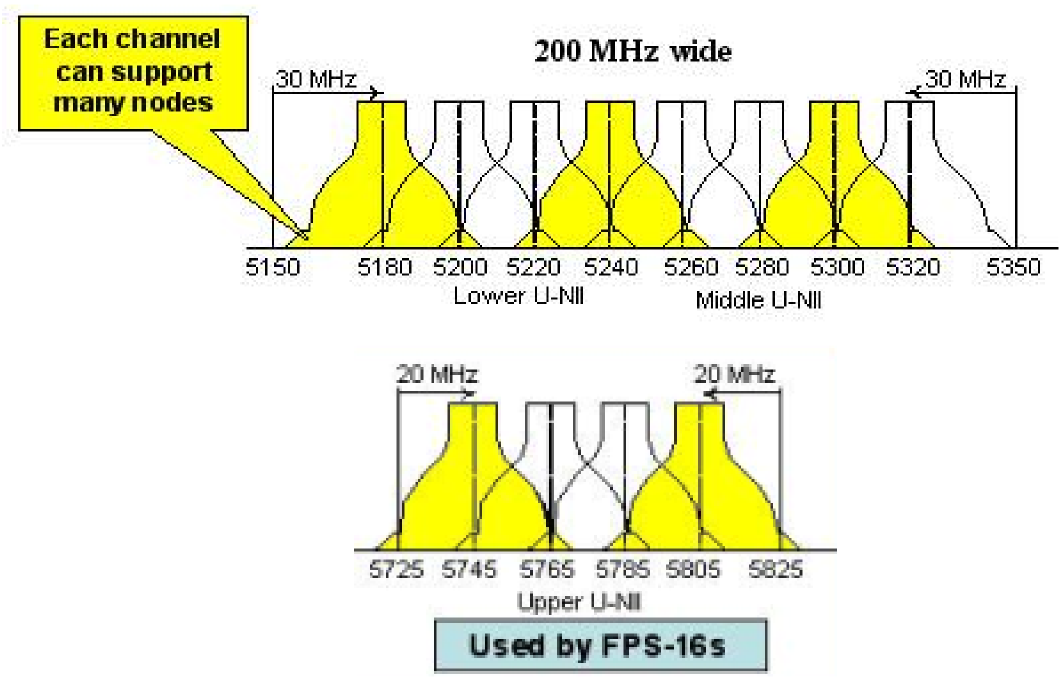


Figure 3. Pictorial Representation of the U-NII Bands

CONEPTS FOR MULTIPLE TARGET VECHILE DATA ACQUISTION

There are several issues that make missile defense testing extremely challenging with respect to telemetry techniques. One is clearly the availability of spectrum, as discussed in the previous section. Another issue is the very long trajectories producing huge slant range distances (when line-of-sight is possible) and over-the-horizon or non-line-of-sight geometries. During "target fly-in," low data rate range safety information and vehicle health status are required, while close to the intercept point higher data rates are required to gather lethality data. A WLAN solution can adjust data rates over-the-air (OTA) to improve link margins and/or to conserve onboard power.

For the case missile defense tests for a single interceptor/single target, 100MHz of bandwidth supports approximately 30Mbps of data transmissions in S-band. An 802.11a concept could support a similar data rate over a comparable increment of spectrum (a single channel in C-band) for 5-15 nodes. Some of the nodes would potentially be relay sites, while some would actually be platforms in the test. It is highly conceivable that the use of multiple WLAN channels would then be used to support multiple interceptor/target tests. The interceptors would be on one channel, while the targets would be on a separate channel. The basic concept for a WLAN, however, is that the nodal structure will be "similar and replicable" in that a basic node design is established and cloned to provide cost benefits and redundancy. If one needs an additional repeater node to support a test, a clone can be inserted with the network quickly re-established. Given that the WLAN is fully 2-way, however, the link must be closed in both directions. Hence, a telemetry ground station, which is normally considered to be passive, becomes active due to uplink transmissions. For notional estimates, WLAN symmetry (in terms of uplink and downlink) in radiated power will be assumed. The practical considerations of radiated power from sites that were heretofore passive must be considered, especially in terms of safety and noise generation at other frequencies.

FUTURE ANTENNA TECHNOLOGIES

Given that test objects will "move across or through" the network, it is prudent to investigate multiple band, electronically steered antennas. The commercial marketplace is driving this technology, and only one example is provided. Paratek Microwave has developed base station antennas suitable for GSM (global system for mobile communications) applications. The existing antennas would have to be reconfigured and re-tuned to other frequencies, but the technology should support such changes. From the Paratech website, transmit/receive gains along the antenna bore sight are ~ 20 dBi, which is dramatically higher than conventional wrap-around antennas with standard materials and fabrication techniques. It will be assumed that antennas of this type will be developed to support the WLAN infrastructure. Furthermore, since we are examining concepts for the future, we will assume that present performance levels will be improved in the future. Hence, we will use a receive/transmit antenna gain of 28 dBi.

MAXIMUM RANGES AS APPLICABLE TO TARGET VEHICLE CASES

Most missile defense target trajectories are classified, hence we will just present the maximum ranges that the "assumed WLAN system" can support link closure for the "a" and "b" standards.

Channel bit rate (Mbps)	1	2	5.5	11
Max total transmit power (dBm)	42	42	42	42
Cable and combiner losses (dB)	2	2	2	2
Transmit antenna gain (dBi)	28	28	28	28
Total transmit EIRP (dBm)	68	68	68	68
Receive antenna gain (dBi)	28	28	28	28
Cable and connector losses (dB)	2	2	2	2
Information rate (dBHz)	60	63.0	67.4	70.4
Required Eb/(No+Io) (dB)	10.4	10.5	8.1	8.1
Receiver sensitivity (dBm)	-90	-88	-87	-83
Propagation effects margin (dB)	10	10	10	10
Max path loss (dB)	174	172	171	167
Max range (free space) (km)	**2299**	**1865**	**1680**	**1105**

Table 1. 802.11b Link Performance.

Channel bit rate (Mbps)	6	54
Maximum total transmit power (dBm)	42	42
Cable and combiner losses (dB)	2	2
Transmit antenna gain (dBi)	28	28
Total transmit EIRP (dBm)	68	68
Receive antenna gain (dBi)	28	28
Cable and connector losses (dB)	2	2
Information rate (dBHz)	67.78	77.32
Required Eb/(No+Io) (dB)	8.73	19.19
Receiver sensitivity (dBm)*	-85	-65
Propagation effects margin (dB)	5	5
Max path loss (dB)	174	154
Max range (free space) (km)	**1047**	**129**

*[http://www.globalsuntech.com/solution/ieee80211/54mbps_platsolution.htm]

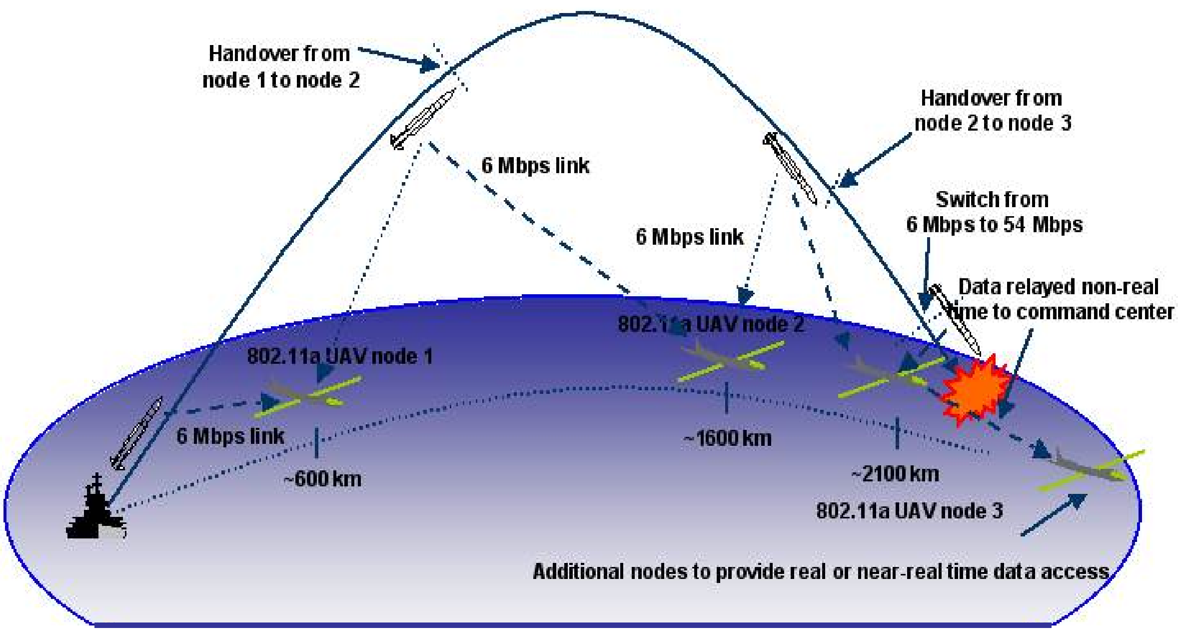
Table 2. 802.11a Link Performance.

Comments on important issues will now be addressed, as if one were to attempt a hardware solution for each of these cases. The distances in Table 1 are far in excess of the typically stated 802.11b maximum range of 1,000 ft. This range is limited by the delay time that the network will accept between repeating nodes, which is normally set at 1 msec. At a distance of 1,000 ft, the air delay time of ~ 1nsec/ft adds up to that stated delay time. However, there are WLAN products where the delay time can be software reset, and such is the case for the Cisco Aironet 350 Series Wireless Bridge products typically used at YPG (Ref 1). The maximum allowable delay time (and, therefore, the maximum range) must be considered if ranges above 40 km are to be used, which is a typical separation distance for infrastructure sites at YPG. The maximum delay time is not typically stated by the manufactures, and it is best determined from actual experience (as in the YPG case).

For the 802.11a link performance estimates, frequency shifts at the receiver must be addressed. The OFDM spreading scheme is normally used for static infrastructure sites where Doppler issues are minimal. A single 802.11a channel using OFDM has 52-subcarriers that are closely nested to achieve high data rates. This close nesting is subject to channel-induced frequency offsets when nodes are in motion. This means that the receiver must be compensated for frequency shifts of “fast movers,” which is not an uncommon problem and which can be overcome. Estimates for missile defense intercept produce frequency shifts approaching 70 KHz, while “a” radios are only designed to accommodate shifts of 15 KHz. Compensating for large frequency shifts may not be of interest to the commercial sector. Such a special receiver may only be of interest to the DoD, however. This difficulty with the “a” physical layer probably restricts experiments on moving nodes to the “b” standard for the near future. The link performances for the two cases are also impacted by larger spreading losses that will naturally occur for “a” versus “b.”

NOTIONAL IMPLEMENTATION

A notional implementation is shown in Figure 4. In this case a target vehicle is fired from a ship with a trajectory that is extremely long such that direct line of sight observation of the intercept point is not possible from the launch point. Unmanned aerial vehicles (UAVs) were postulated as airborne infrastructure sites. UAVs will be used in the future as range safety assets (rather than manned aircraft that have limited station keeping times) and as high altitude optical tracking platforms. The UAVs can also be used to buffer data to accommodate network capacities and link margins. With buffering as an option on the UAVs, data can be passed at slower rates and/or at different channels or at different frequencies using different standards. For example, a dual-mode WLAN product (such as the Cisco Aironet 1200 Series) would be capable of receiving data at very high rates (the "a" standard) and then buffering data for transmission at lower data rates where link margins are more favorable (the "b" standard). The notional example also utilizes OTA changes in the data rate to preserve power and to improve link margins. In Figure 4, node 1is positioned to address the OTH problem of relaying data down range for safety, and the lowest data rate (6 Mbps) is used. Further down range a hand-off is made to node 2, again addressing OTH problems. Finally, a hand-off to node 3 occurs with OTA command to increase the data rate to 54 Mbps, which is needed at intercept and which can be accommodated due to reasonably short transmission distances to node 3. Node 3 could relay data to another surface ship or to a terrestrial site.



CONCLUSIONS

This paper has discussed some notional cases of maximum range at which WLAN technologies could be used. It was assumed that air delay times were increased and that advanced electronically steered antennas were used. A single power level was examined for several data rates common to the 802.11 standards. A long list of issues was annotated with several of these being discussed. It is apparent that very high data rates can be supported even with a large number of nodes. It seems reasonable that experiments with the common 802.11b standard be conducted, but it is also clear that the higher data rates of the 802.11a standard are very attractive. The spreading techniques of each standard are not the same, and the "a" receivers must be developed to accommodate nodes that are located on fast moving test assets. It is also certain that new base station antenna technologies must be reconfigured from the commercial sector formats.

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