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Research Results

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Study of High-Speed Wireless Data Transmissions for Railroad Operation

SUMMARY

With the widespread deployment of high performance wireless data network technologies (such as Institute of Electrical and Electronics Engineers (IEEE) 802.11a/b/g, 802.16e, etc.), it has become feasible to utilize these standard-based wireless technologies for applications desired by the railroad industry for improving operations effectiveness, monitoring and control, and safety. Before any of these wireless systems are employed, however, serious questions must be answered to assure that the railroad requirements of mobility, throughput, coverage range, Doppler effects, and response times are met.

The University of Nebraska, under a grant from the Federal Railroad Administration (FRA), has been studying the feasibility of using 802.11a/b/g-based wireless networks for mobile railroad environments. A 3.5-mile test bed has been designed and implemented with a series of access points in the Burlington Northern Santa Fe Railroad (BNSF) Hastings Subdivision near Lincoln, NE, to support this study. The test bed has complemented the theoretical study supported with in-depth computer models and simulations to measure and analyze network throughput of 802.11a/b/g for trains under different velocities. Simulation results have been compared and verified with test bed measurements to analyze performance characteristics of 802.11-based networks for mobile trains. Results and analysis show that even though the system throughput of 802.11 standard decreases under high velocity, it can still support railroad applications if the coverage range is provided. Therefore, an 802.11-based wireless network can support real-time Internet accessibility for trains' crew, passenger, and railway workers, improving railroad operating safety and efficiency.

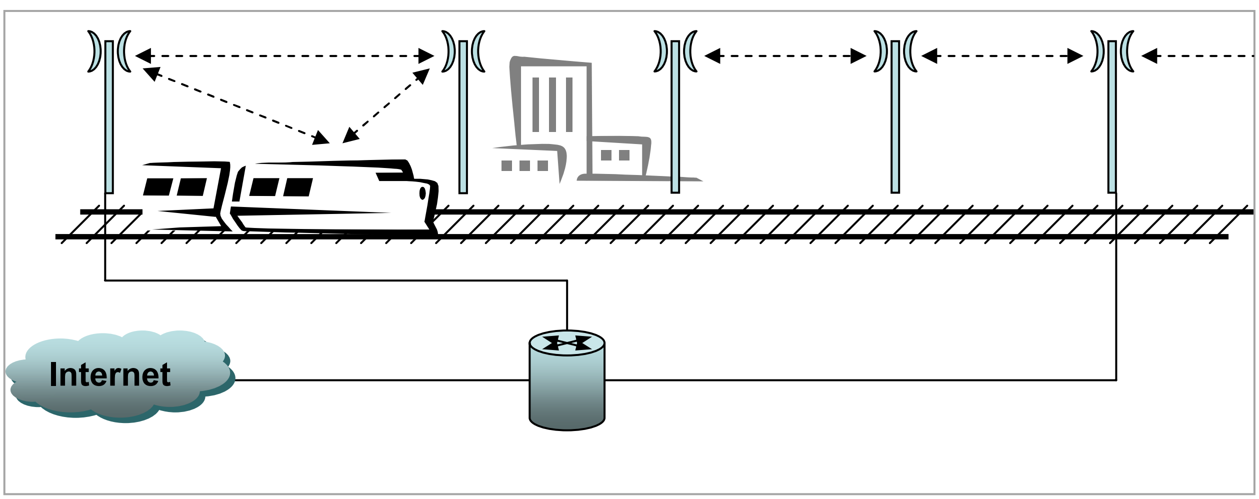

Figure 1. High-Speed Wireless Data Network for Railroad Operation

INTRODUCTION

Near real-time communication between ground infrastructure and moving locomotives and other vehicles provides rapid response capability to unexpected events. It may prevent injury or minimize the impact of an incident. Other real-time communications, such as event recorder download, onboard health monitoring system for locomotives and trains, and better communication between the dispatching office and trains, can improve the efficiency of railroad operation. Newer broadband wireless technologies offer the potential to support this type of communication. Many major issues, however, remained unanswered for the suitability and performance of these networks.

This study with field test data has investigated these issues and its feasibility for railroad applications before deployment.

TECHNICAL DESCRIPTION

Simulation

This study investigated the 802.11b standard under mobile scenarios for a variety of velocities with computer modeling. The indepth models were designed and implemented to incorporate Rayleigh fading distribution and Doppler shift into the NS-2 simulation environment in order to provide an approximation of bit error rates based on the channel and environment characteristics. Support for multiple channels, channel scans, and switches, as well as data rate adaptation, were also added as enhancement of the models.

802.11a/b/g were designed and coded in the model. Physical layer characteristics were simulated to determine the impact of noise, fading, and Doppler shift, as well as to calculate effects of shadowing, Rician fading, and Rayleigh fading. Medium Access Control (MAC) and Data Link Layer protocols in the model implemented functions, such as fragmentation and de-fragmentation, data retransmission, multi-rate support, multiple channel scanning, synchronization, power management, authentication, association, and handoff. The simulation results display the performance evaluations of mobile scenarios under a variety of velocity and transmission configurations. These results would demonstrate the low and high-speed impacts on system throughput for different data rates under 802.11b. This includes data rates of 1 to 11 Mbps for velocities up to 90 mph.

Test Bed

A test bed was designed and implemented to provide field data based on industry implementation of 802.11a/b/g. The test bed was chosen carefully to include different terrains. Measured data from the test bed was used to complement analysis of theoretical studies and simulation results to understand network throughput under the real operating environment.

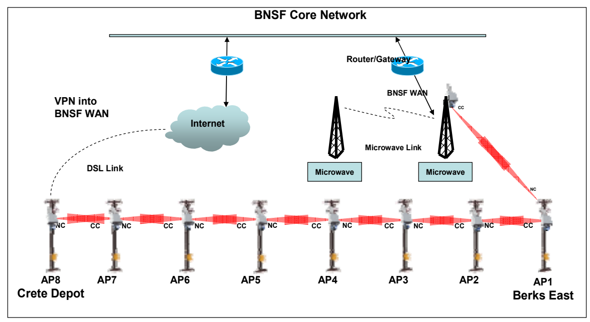

Figure 2. Test Bed with Planted 802.11 Access Points in Test Bed

A 3.5-mile section at Crete, NE, in the BNSF Hastings Subdivision was chosen for its close proximity to the university and challenging environment with heavy foliage, curves, and surrounding hills. BNSF contributed by installing the hardware, including the 5.7-mile microwave tower extension and link. The test bed utilizes the 802.11 technology to support wireless connectivity between moving trains and fixed access points. The test bed was also designed to support equipment from different vendors, as well as upgrading to the upcoming technologies such as the 802.16e (mobile WiMAX) and 802.20. Several Class I railroads and the Association of American Railroads (AAR) were involved in the design of the test bed and the selection of the vendor. Strix Systems equipment was finally selected for the network. A total of eight access points was deployed in this 3.5-mile segment. The farthest space between access points is approximately 1.2 miles where the track is tangent, but, in curves, they have to be deployed much closer together for seamless coverage. Figure 3 shows a curve where access points have to be closer because of the curve obstruction. Figure 4 shows the antenna coverage for this 3.5-mile stretch of track.

For most field tests, a hy-rail vehicle was used to represent a train. For the high-speed test, the vehicle traveled on a highway adjacent and parallel to the railroad track. Wayside computer equipment connected to this network was used at one end of the test bed to receive from and transmit data to the hy-rail vehicle. A series of tests was performed, including operational verification, various stationary, and mobility tests, between October 2005 and December 2006. The throughputs in terms of Mbps were measured and compared to the maximum transmission rate of 11 Mbps.

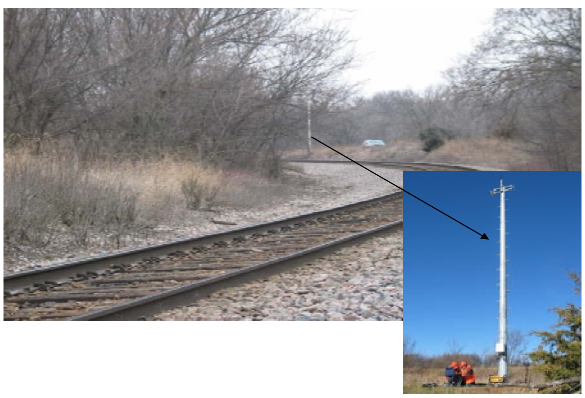

Figure 3. Access Point Antenna Pole on the Farther Side of Curve

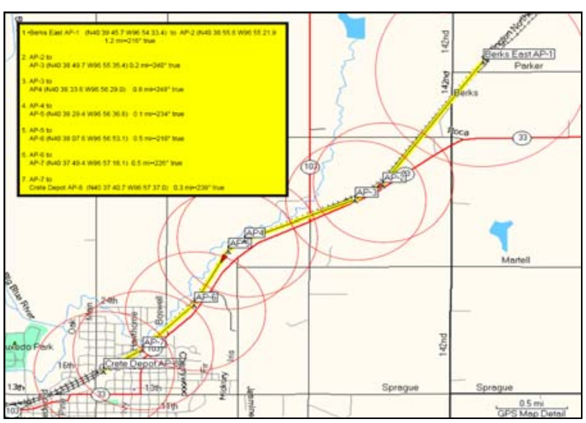

Figure 4. Coverage in the Test Bed

RESULTS

Figure 5 depicts the throughput measured under 55 mph in the test bed compared with the simulation results for a similar scenario. It clearly shows that the simulation results match measured results from test bed. This is one of the sample results in verification of the developed simulation model.

Figure 6, as a part of the actual field test results, illustrates the round trip delay time of a message. As the vehicle was moving away from Access Point (AP) 8 (Crete Depot), the round trip time for a message was measured as a function of the distance from this access point. Generally, as expected, as the distance increases, the delay increases, but not significantly.

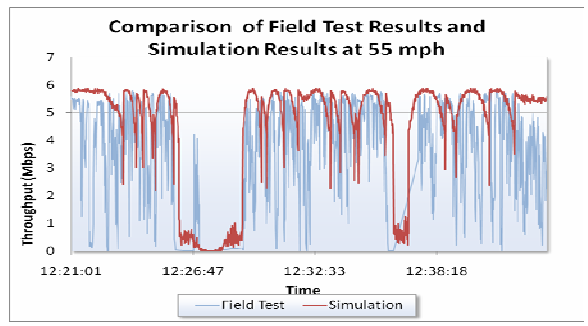

Figure 5. Sample Simulation Results

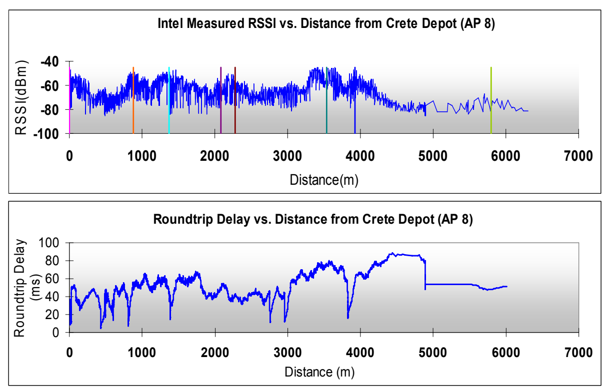

Figure 6. Received Signal Strength Indication and Round Trip Time

Figure 7 shows the throughputs as the vehicle is farther from AP 2. The throughput was measured with a stationary vehicle. Figure 8 shows the throughput results with velocities of 45 and 90 mph. The impact of handoff is clearly shown, and it also illustrates the insignificant impact of higher velocity on throughput. Additionally, audio and video applications were tested with this network. Out of a possible Mean Opinion Score of 5, the quality of the audio streaming was rated around 4.5 consistently. The video streaming sent from the caboose or the highway vehicle was recorded with good quality and with little break in the picture composition.

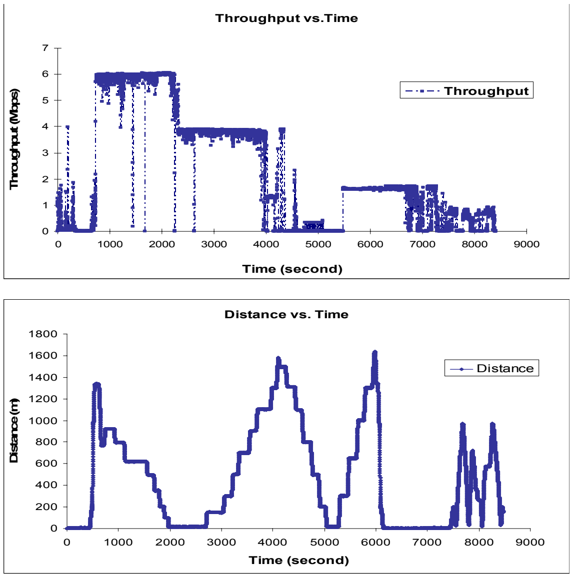

Figure 7. Stationary Test of Throughput as a Function of Distance from AP

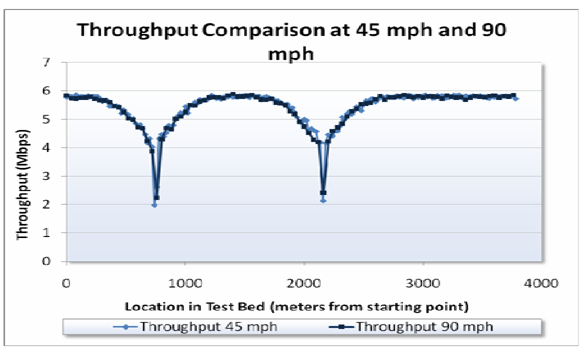

Figure 8. Throughput Comparison between 45 and 90 mph

CONCLUSIONS

Both the modeling and field tests showed that the broadband communication technology based on IEEE 802.11a/b/g protocols can be applied to railroad operation for high-speed mobile data transmission. Future protocols, such as 802.16 and 802.20, will enable significantly longer spacing between access points, making this type of infrastructure buildup a viable data communication network for applications enhancing safety and efficiency of railroad operations.

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