A Measurement Study for Link Rate Modeling and Handover Optimization for Vehicle Communications over IEEE 802.11g Infrastructure Network

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Extended Abstract

Persistent communication has become increasingly important to modern automobiles in today's heavily utilized road systems. Via network communications, drivers can acquire a myriad of information to enhance safety, efficiency, and productivity on the roads. For many years automobile manufacturers have equipped cars with satellite or cellular technologies for emergency communication, telematics, and remote diagnostics purposes. Despite a nearly ubiquitous coverage, these technologies do not provide sufficient bandwidth to cope with the increasing complexity of vehicle information services. With the recent deployment of IEEE 802.11 based municipal network infrastructures, various measurement studies have been conducted to assess their ability to enable broadband communication inside moving vehicle [1-3]. For cars moving at various speeds, these studies have commonly considered: 1) IEEE 802.11b radios, 2) network association and transport layer throughput performance, and 3) no handover for persistent end-to-end communications. While these studies have accurately characterized the performance achievable with today's commonly available devices, they have not revealed sufficient insight to determine: 1) an accurate mobility aware link rate and quality model, 2) the handover behavior across a series of access points (APs), and 3) strategies for link rate and handover optimization during vehicle mobility. This paper presents early results from a measurement study conducted to address these challenges. To achieve these objectives, the measurement study considers IEEE 802.11g with all data rates enabled, and focuses on capturing short-term throughput impacts due to link rate adaptations and link events associated with handovers.

Experiment setup: The measurement study was conducted on an IEEE 802.11g network established at the BMW high speed test track facility at Spartanburg, SC. The network consisted of three Cisco 1200 series IEEE 802.11a/b/g pole-mounted access points placed 6 feet above ground at 400 feet distance intervals along the test track. The APs were configured with the same ESSID and a common channel (Channel 1), and they were connected with a common Ethernet backhaul. The mobile client was an IBM Thinkpad T60 laptop with Ubuntu 7.04 Linux operating system, a built-in Intel Pro/Wireless 3945ABG Wi-Fi interface (driver: ipw3945 v1.2.1 from http://ipw3945.sourceforge.net) for data transfer, and an external Cisco Aironet ABG PCMCIA Wi-Fi interface (driver: Madwifi v0.9.3.1 from http://madwifi.org) for link events monitoring. The Ethernet backhaul extended 800 ft. using 3 Cisco Catalyst 2950 switches, one of which acts as a DHCP server. A second laptop was connected to the Ethernet as a server for iperf. The network is illustrated in Figure 1. The mobile client was held by a person sitting in the front passenger seat. The client's transmit power was 16 dBm (40 mW); the maximum and minimum AP transmit powers (30 mW and 1 mW) were both studied.

Experiments were conducted under three scenarios with the mobile client: 1) stationary at selected locations on the test track, 2) walking through the test track at controlled speeds, and 3) driving through the 1200 ft. test zone at constant speeds of 20 and 40 miles per hour (mph), respectively. For each scenario, UDP upload, UDP download, TCP upload, and TCP download experiments were performed respectively. The experiments were performed with an iperf v.2.0.2 client on the mobile client initiating UDP or TCP connections with the iperf server on the Ethernet. Wireshark v.0.99.5 is set up on the mobile client to monitor all packet transmissions (in Channel 1) via the external Cisco interface. The radio received signal strength indication (RSSI), per transmission link rate, and missed AP beacon count were also recorded.

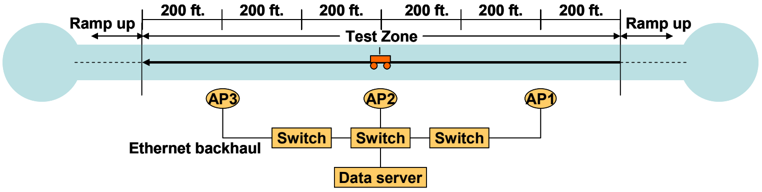

Figure 1. Organization of vehicle IEEE 802.11g infrastructure network testbed (not to scale).

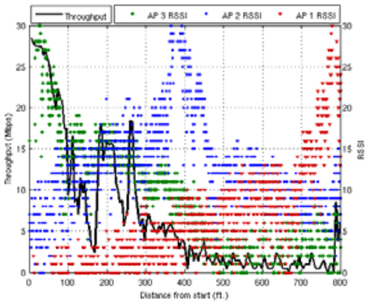

Figure 2. Walking throughput and RSSI.

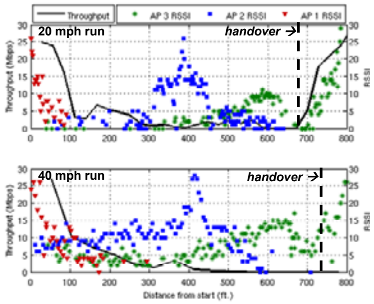

Figure 3. Driving throughput and RSSI (top: 20 mph, bottom 40 rpm).

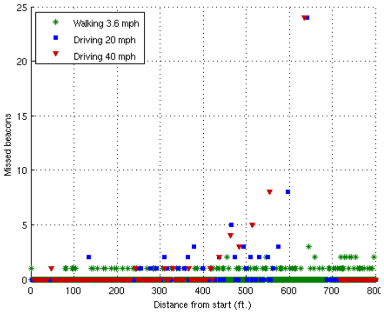

Figure 4. Missing beacons.

Results and conclusions: Below presents selected results from the experiments. All results shown here were obtained with the minimum AP transmit power (1 mW).

Scenario 1: Stationary experiments showed that throughput decreased monotonically with increasing distance from the associated AP. With the ipw3945 driver's procedure, handovers occur long after the throughput has degraded substantially. The per-transmission link rates over time were observed to closely resemble the throughput curve.

Scenario 2: The achieved UDP download throughput and the client's RSSI as the client walked from right to left across the test zone at approximately 5 feet per second are shown in Figure 2. Key findings: No handovers were observed and the client remained associated with AP1 in all walking experiments. Throughput dropped substantially as the client moved away from AP1.

Scenario 3: The achieved UDP download throughput and the client's RSSI as the vehicle drove from right to left across the zone at 20 and 40 mph are shown in Figure 3. Key findings: One handover from AP1 to AP3 occurred in most driving experiments. The handover occurred near the end of the run due to 24 missed beacons (Figure 4, at 686 sec in 20 mph run, at 741 sec in 40 mph run). Similar to the walking scenario, throughput decreased with increasing distance from the associated AP. Still, the low throughput periods prior to handover suggested a suboptimal mode of operation. Different vehicle speeds result in varied throughput dynamics both before and after a handover, as observable in Figure 3.

Handover analysis: The differences observed in the handover behaviors among the stationary, walking, and driving experiments have attracted our utmost interest. The ipw3945 driver initiates handovers under two conditions: 1) if 8 consecutive beacons are missed, it initiates the *roaming procedure* to probe in the current channel for any APs that have the same ESSID as and a higher RSSI than the current AP. If at least one is found, it associates with the one with the highest RSSI. 2) If 24 consecutive beacons are missed before roaming has occurred, it *disassociates* with the current AP and probes in all channels for APs with any ESSID and a higher than current RSSI to *associate* with. As confirmed in the experiments, the number of missed beacons, the link rate, and the achievable throughput were closely correlated with the RSSI, which was dependent on the client's distance from its associated AP.

Future work: The study's primary objective is to acquire sufficient insight of the IEEE 802.11g radios' link rate dependency on the distance and speed of a moving vehicle, and their handover dynamics across a series of infrastructure APs that provide continuous coverage. Results from the study are useful for constructing quantitative link rate models based on client-AP distances and relative speeds for studying the performance, capacity provisioning, and handover strategies for vehicle infrastructure communication networks.

References:

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