Abstract—Datacasting employs the excess bandwidth from digital television signals for use in one-way data transmission, and it is being used successfully for high-speed downloads at fixed locations. There is considerable interest in extending datacast usage to mobile users, although there are reception challenges in the mobile environment that can significantly impact system performance. To explore the feasibility of using datacasting in this environment, datacasting receivers and data logging equipment were installed in emergency vehicles to record performance characteristics over a wide range of operational conditions. Summary conclusions from that study are described in this paper along with details about the network infrastructure and equipment used.

Although datacasting provides only a downlink channel, it can be interfaced with other channels so as to form a two-way link. In the work reported here, datacasting was coupled with a broadband cellular channel to successfully provide a two-way data channel.

It is important to note that this paper addresses the use of conventional datacasting, which is particularly sensitive to multipath interference. For example, conventional datacast reception is not possible when the receiver is in motion. Newer forms of datacasting that are less susceptible to multipath are currently under development and should be on the market in the near future. Consequently, some of the limitations of conventional datacasting reported here may not be factors with the newer versions of datacasting.

Index Terms—Datacasting, Mobile, Antenna, UHF, Rain Effects, 8VSB modulation

I. INTRODUCTION

Datacasting is the term used to describe the transmission of data that can be encoded into the excess bandwidth from digital television signals. Bandwidth is left over when the signal being transmitted does not occupy the entire allotted bandwidth for the channel, and this generally occurs when the television image does not contain a high degree of motion. This excess bandwidth provides for data rates of up to around 2 Mb/sec, and the data can be retrieved using relatively low-cost equipment within the television station coverage area. Data carried via datacasting can be encrypted and sent only to targeted receivers, making this form of data transmission desirable for a range of commercial and government applications.

Datacasting is being used increasingly for one-way, point-to-point data transmission to fixed locations; the work reported here involves the practical considerations associated with using datacasting in mobile environments, and in particular emergency vehicles. These practical considerations include the relationship between receiving equipment (viz., the antenna, preamplifier and receiver) and reception for the expected range of operational conditions.

Datacast reception is quite vulnerable to multipath interference caused by terrain and local scattering structures such as buildings and vehicular traffic. Because of this, there are locations within a television transmitter’s coverage area where datacast reception is not possible. Propagation models capable of predicting small-scale multipath effects are not practical or sufficiently reliable to estimate datacast performance over large geographical areas, so assessing the datacast channel availability through actual measurements is considered to be the only viable option.

The datacast signal for this study is generated by the UNH-licensed Public Broadcasting Station, New Hamp-
shire Public Television (NHPTV), and personnel from NHPTV were actively engaged in the work reported here.

Datacast installations, using the equipment described in Section III, have been made in 9 New Hampshire State Police vehicles. Those vehicles had already been outfitted with computer and networking equipment developed as part of an effort known as Project54 [1]. Project54 equipment enables electronics within a vehicle to be controlled by a single computer, which affords options such as voice-activation, device coordination and data logging. Since most of the in-car networking and computing infrastructure was already in place, adding the datacasting equipment and making the necessary modifications to the data logging software was straightforward.

The mobile datacast evaluation effort described in this paper was carried out in the state of New Hampshire. The result of this work affords a quantitative assessment of the capabilities and limitations of datacasting in the mobile environment for a wide range of operational conditions. Data have been collected over different terrain types (New Hampshire varies from relatively flat, sea-level terrain to rugged mountains containing the highest peak in the Northeast USA) and different weather conditions (data collection spanned the New England summer, fall and winter seasons). Through the mining of the extensive data collected as part of this effort, it is clear as to the conditions where datacasting will and will not provide a robust and dependable data link for the mobile receiver.

The performance of datacasting as part of a two-way channel was also evaluated in this study. Uplink was provided by a broadband cellular channel in the vehicle, and the downlink channel was provided by datacasting. A conclusion from this facet of the work is that this type of configuration can work in a robust manner, and can afford a number of benefits in terms of total channel capacity, security and capability to send multicast data to a large number of receivers. While the two-way configuration was evaluated using a broadband cellular connection, it should work well with any other form of wireless connection.

II. Datacast Network Infrastructure

Much of the network infrastructure on the transmitting end was in place and configured by NHPTV. Figure 1 depicts how data are routed from the source to the receiver in the field. The source file can reside on any computer networked to the Internet, and that file can be placed on the datacast file server using the appropriate password or automated using pull technology residing on the server. Once a file is placed on the file server, which is located at NHPTV, the file server packages the file to be transmitted and sends the data to the IP encapsulator and multiplexer, where the file is converted into appropriately sized IP packets and weaves those packets into the MPEG2 data stream appropriate to digital television (DTV) transmission. The DTV stream is sent to the transmitters via microwave uplinks and is delivered over the propagation channel to the datacast receivers located within the emergency vehicles. The DTV receivers monitor the DTV stream and extract the data transmitted over the datacast program information channel (PID), decodes the stream back into IP packets, reassembles those packets back into files and stores the files on the local receiving computer.

The broadcast signal measured in this study is radiated from the Saddleback Mountain broadcast facility licensed by NHPTV. The signals in this study were radiated from an antenna positioned 44.9 meters above ground at a frequency of 731 MHz (Channel 57) with an effective radiated power of 589 KW.

III. Selecting In-Vehicle Equipment For Measurements

One of the guiding principles used in selecting in-vehicle equipment for this study was to use off-the-shelf items, and to keep costs as reasonable as possible. Further, there was to be a standard equipment configuration that would enable reception over the entire UHF television band. This latter constraint mandated the use of a broadband antenna, which eliminated the possibility of using smart antennas to boost gain and lessen noise. Consequently, one of the challenges in identifying antennas for this application was to find ones that would cover the entire UHF television band (=200 MHz to 1 GHz). One of the drawbacks to this is that broadband antennas tend to have a lower gain which necessitates the use of a pre-amplifier, and preamplifiers introduce some degree of noise.

Another challenge in selecting antennas is that the datacast signal is horizontally polarized, which makes it more...
difficult to achieve the desired azimuthally-isotropic radiation pattern. An isotropic pattern is desirable for this application so that reception will not vary with vehicle heading. If the signal were vertically polarized, a simple, electrically-short whip antenna would be the obvious solution.

Two of the low-cost antenna designs that will operate over a wide bandwidth and provide a nearly isotropic radiation pattern for horizontal polarization are a short folded dipole and a magnetic loop antenna. These are the two designs used for this study, the electric-field antenna being an off-the-shelf product and the magnetic-field antenna being custom made for this application. Half of the installations for this study were made using one of the two designs, which are pictured in Figure 2. The off-the-shelf antenna [2] is intended for mobile TV reception and costs around $100 USD including preamplifier. To avoid interference with the horizontally-oriented light bar, datacast antenna mounting was restricted to the trunk. A rough measurement of the antenna pattern, subsequently verified by computer model, revealed a pattern that reasonably approximated an isotropic pattern.

Figure 2. Electric and Magnetic Field Antennas Mounted on Police Vehicles. The H-Field Antenna Is Positioned Just in Front of the Vertical Whip.

A final challenge in selecting antennas was to identify ones that will stand up to the rigors of the mobile environment. Specifically, an antenna should be mechanically strong so that it will not be susceptible to damage in normal operation and so that it will not be an easy target for vandals. Appearance and ease of installation were also considerations in selecting antennas.

Both the electric and magnetic field antennas demonstrated similar reception characteristics, although the size and appearance of the magnetic-field antenna makes it preferable from an installation perspective.

As noted above, a preamplifier is typically needed for electrically short antennas such as the ones used for this study. Since the noise added by the preamplifier (noise figure) reduces the signal-to-noise ratio, and hence reception coverage area, the noise figure was evaluated for several off-the-shelf preamps. Figure 3 plots the noise figure measured in this study against manufacturer specifications and includes the preamplifier cost. Given the desire to contain costs, a preamplifier with a noise figure of approximately 2 dB was selected, although a quieter preamplifier can always be used in fringe reception areas.

To enable an unbiased assessment of antenna performance, all antennas used the same preamplifier for the signal measurements reported here.

Figure 3. Plot of Measured versus Advertised Noise Figure for Variously Priced Preamplifiers.

The receiver selected for this study was the Broadband Technologies AirStar 5th generation datacast receiver, available through Triveni [3] at a cost of around $170 USD. This receiver was selected primarily due to the researchers’ past experience using it and its earlier version.

The total cost to install datacasting capability into a vehicle for this study is in the neighborhood of $300 USD not including the computer to which it was connected, and that cost will likely decrease in the future.

IV. RAIN EFFECT ON DATACAST RECEPTION

Conventional wisdom suggests that rain effects will not appreciably degrade radio reception at UHF [4], and hence it might be assumed that rain will not affect datacast performance. Accordingly, while a lot of work has been performed to characterize rain effects for earth-satellite links and microwave terrestrial links (for example [5]), very little documentation exists regarding rain and relatively-short, UHF terrestrial links such as the datacast link. However, in the early part of this study, datacast reception outages were observed to coincide with rainfall. These observations are surprising at 731 MHz (Channel 57), particularly considering that some of the outages occurred for line-of-sight propagation paths under 20 km. Because the overall objective of this study was to investigate the capabilities and limitations of the datacast system, gaining an understanding of the rain-related outages was considered to be a priority.

An example of a rain-induced drop in signal-to-noise ratio (SNR) is evident in Figure 4. While the parameter speci-
fied by the receiver is called SNR, it is more likely a measure of Desired-to-Undesired (D/U) signal ratio. The calculation is made in the receiver using an approach similar to finding the closure in the eye pattern, and it will give a lower SNR reading with either increased noise or multipath interference.

The data in Figure 4 were collected by a BBTI AirStar Generation 5 receiver during heavy rainfall which was color coded on radar to have an intensity of 50 dBZ as seen in Figure 6. The color coding on the map represents dBZ, which is an indication of equivalent reflectivity measured by the weather radar system. 50 dBZ corresponds to a rainfall rate of at least 1.75 inches per hour.

The pronounced dip in SNR is significant, particularly considering the short distance between the transmitter and receiver (23 km). This degree of signal degradation is sufficient to make datacast reception unavailable at most receiver locations.

Significant reduction in SNR is also seen with rain events of relatively low intensity, even when the storm cell is not located between the transmitter and receiver. This suggests that backscatter from storm cells can generate enough multipath interference so as to significantly degrade reception. Specifically, reductions in SNR in excess of 15 dB have been observed when the line-of-path is clear and a storm cell is located approximately a mile behind the omni-directional receive antenna.

To test the hypothesis about backscatter being the mechanism for datacast outages during rain events, a rooftop monitoring setup (Figure 5) was installed to include two directional antennas and one isotropic antenna to record key parameters defining datacast signal robustness (e.g., signal strength and signal-to-noise ratio). One of the directional antennas was pointed towards the transmitter and the other was pointed away from it. Both directional antennas have gains of around 6 dBi, with front-to-back ratios in excess of 10 dB. The isotropic antenna (not shown in the figure) was used as a reference and to evaluate how the in-vehicle system would perform.

The purpose of the backward looking directional antenna was to sense the backscattered field, which was referenced to the signal from the transmitter that was provided by the forward looking directional antenna.

Analysis of the data provided by the rooftop monitoring setup revealed that multipath signals backscattered from
storm cells were the likely cause of the datacast channel outage. As the backscatter signal level increased, the SNR for the receiver connected to the omni-directional antenna began to diminish, oftentimes to the point where the receiver lost lock, which ended data communication between the transmitter and receiver.

The data obtained from the rain-effect modeling effort suggested that modifications to the datacasting system to mitigate or reject the multipath signal would eliminate the rain-effects. Two options are being investigated. The first involves modification of the antenna to reject multipath sources; the second involves adoption of a new, more robust modulation scheme.

Further work to develop a more suitable datacast antenna has been undertaken in hopes of mitigating channel degradation due to rain effects. Specifically, an antenna with increased gain near the horizon, in the direction of the transmitter, will increase desired signal level while filtering out undesired backscatter. Such an antenna will increase the coverage area of the datacast system by adding system gain without adding noise. As part of this study, three antenna designs were investigated. A traveling wave antenna, an array of loops, and a horizontally-polarized bi-conical antenna were explored in a computer model, but none of these designs have been physically constructed yet. The biconical antenna shows the most promise in overcoming the design challenges outlined above, and this antenna will be explored more in the future.

V. NEW DATACAST MODULATION SCHEMES

Due to its sensitivity to multipath interference, particularly time-varying multipath, datacast reception using the current 8-VSB [6] modulation scheme is only practical when the vehicle is not in motion. This may be the greatest limitation associated with using datacasting in the mobile environment. However, this limitation may be mitigated if the proposed Advanced-Vestigial Side-Band (A-VSB) [7] or MPH [8] modulation schemes are adopted. The additional error correction and training data added to the data stream with these approaches will purportedly enable reception while in motion, albeit at a cost to the data rate. For example, a 1.5 Mb/sec data stream will only yield around 375 Kb/sec of useable data. These modulation schemes are being considered specifically to facilitate mobile television reception.

It is a logical conclusion that if the new modulation schemes are less susceptible to multipath they will be more successful at rejecting the multipath energy that is causing the datacast rain-effects.

Future work is planned to implement and evaluate the new modulation schemes. If they perform as well as early testing indicates, they will enable robust reception while in motion and they will mitigate rain effects.

VI. DATACAST RECEPTION IN THE MOBILE ENVIRONMENT

Datacast installations, using the equipment described in Section II, have been made in 9 New Hampshire State Police vehicles.

The data logged in the vehicles provided detail as to where and when the datacast and cellular channels were available. Position data were provided by GPS, and datacast robustness was determined by signal-to-noise ratio. Files of varying size and type (ASCII, audio and streaming video) were periodically sent to all vehicles in the study to assess channel throughput.

The final results of the data logging effort were maps showing where datacast reception was possible. Importantly, because data were collected repeatedly by different vehicles and under different operational conditions, a realistic assessment of channel reliability was afforded.

Coverage maps can be generated in a wide range of formats. For example, Figure 7 shows datacast coverage from the Channel 57 transmitter for most of the state of New Hampshire. As expected, the location of data points corresponds to the major roadways patrolled by the cruisers, and each point plotted represents a location where the averaged signal-to-noise ratio collected at that location was either above an empirically-derived reception threshold (green dot) or below it as indicated by the failure of the receiver to lock (red-dot).

The signal-to-noise ratio values used in generating the coverage maps often came from measurements over time by a single vehicle, and/or from multiple vehicles collecting data at the same location (within the 11 meter resolution of the GPS equipment used in this study). Consequently, each dot on the map may represent the average of many individual measurements.

Figure 7. Datacast Coverage Map for Southern New Hampshire.
Figure 8 plots estimated television coverage for the entire state. The estimate values plotted were obtained from the Longley-Rice propagation model and give a reasonable approximation of coverage area for stationary television viewers. Referring to Figures 7 and 8, it is evident that the coverage area for mobile users is generally less than the predicted coverage area. There are two fundamental reasons why mobile datacast coverage using low-cost equipment will be less than stationary television coverage. The first reason is that stationary reception is generally obtained using directional antennas with gains of 5-15 dBi which are elevated so as to provide line-of-sight propagation paths. The non-directional datacast antennas elevated at trunk height are not as conducive to good reception.

Figure 9. Datacast Reception Superimposed on Satellite Photo for the Vicinity of Concord, New Hampshire.

These types of plots can be zoomed in to show even more precisely the locations where reception is possible. The location shown in Figure 9 is particularly challenging from a reception perspective because of multiple shadowing terrain features.

VII. TWO-WAY DATACAST SYSTEM

The two-way transmission system developed utilizes datacasting as a download channel and a Verizon cellular modem as an upload channel. The field testing of this system was not as extensive as the one-way datacast coverage study, but gives a confirmation that the system is feasible and operational. The system was installed in a single vehicle and stopped at various locations throughout the state. A data request was made via the cellular upload channel, and a Yahoo street map referenced to the GPS location of the vehicle was downloaded via the datacast channel. The results of these measurements are seen in Figure 10. A red dot represents a location where two-way communication was not available, and a green dot represents a successful two-way, request and download transmission.

The knowledge gained from the limited two-way coverage study is a proof of concept. The software was successful in the field at many locations. Because the Verizon Wireless cellular modem coverage is nearly ubiquitous in the State of New Hampshire, the failed transmissions in the two-way coverage study were due to the poor reliability of the datacast signal in the mobile environment, not an unavailable upload channel. In fact, cellular modem coverage was available at all locations where a test was performed. Causes of a failed datacast transmission include poor propagation circumstances, constant moving nearby vehicles causing multipath interference, and very slow data rates due to being on the threshold of reception.
VIII. CONCLUSIONS

The purpose of the datacasting study was to investigate the feasibility of datacasting as a reliable, high speed communication system for mobile users. While the datacast system in its present form has limitations for use in that environment, it has potential for fulfilling an important need.

Datacasting can provide an addressable, high-speed downlink channel to mobile users over a wide geographical region with reasonably-priced, in-vehicle equipment. Even in its current form, a signal is available in a sufficient region of a television transmitter’s coverage area to enable it to be a useful tool for disseminating large quantities of data. The improvement in channel performance that will likely result from new modulation schemes and antenna designs should make the datacast channel a valuable and dependable resource for mobile users.

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REFERENCES

[1] Information about Project54 can be found at its website: http://project54.unh.edu/

[2] The antenna model is a Wintenna Silhouette 747A, available from Wintenna, Inc., 113 E. Shockley Ferry Road Anderson, South Carolina 29621, USA


[6] 8-VSB stands for 8 Level Vestigial Sideband, and it is the current standard for the modulation format used by digital television. A good description of 8-VSB can be found at: www.broadcast.net/~sbe1/8vsb/8vsb.htm
