Wireless issues in ITS

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Abstract:

In this presentation we provide an overview of wireless related issues and technologies for Intelligent Transportation Systems (ITS). We then consider a number of examples of recent and ongoing relevant research performed at the Ohio State University contributing to this area.

Introduction:

The area of Intelligent Transportation Systems (ITS) covers the use of computer, communication, control and related technologies to transport people and goods in a safe, fast and reliable way. Today, unless otherwise stated, ITS refers to roadway transportation.

The development of wireless technologies is one of the key enablers of ITS. In this presentation we shall first consider the different needs for wireless technologies for ITS mainly through present day examples and our near-term predictions. We shall then review some of the technologies being considered at the Ohio State University.

Wireless technologies, although always for *information transmittal,* can be further categorized based on how they are going to be utilized. As such, we propose the three following categories:

1. Movement related
2. Traffic related
3. Passenger related

Movement Related Wireless Technology :

In this category we consider the technologies that help the real-time driving phenomena for cars, trucks, busses and other specialty vehicles (e.g. snow removal equipment). The following are technologies mostly for relative location measurement:

- Magnetic nails
- Radar reflective stripe
- Magnetic tape
- Radar for reflection sensing
- Laser for reflection sensing
- Radar for imaging
- Active transponders
- Waveguides
- Live wires
- Car-to-car communication
- Infrastructure-to-car communication

A recent development has been the use of GPS and precision map following for car driving. As compared to the above list, which is basically for relative positions, map referral methods could be considered as providing absolute position measurements.

Most of the technologies listed are derived from the push for Automated Highway Systems (AHS), although other technology drivers could be interest in individual public vehicles, automated test systems,, convoying for trucks or busses, large-scale warehousing, to name a few.

Let us briefly consider the use of radar, one of the main technologies here. Radar can be used first as the sensor for the steering of a car (truck, or bus). One of the early applications was as a sideways sensor, measuring the distance from a guide-rail by the side of the road. The real-time measurement could be then used in a feedback loop, controlling the orientation of the steering wheel. This type of system was later utilized in a test track for trucks.

Another use of radar would be in determining the distance and speed of a vehicle we may be following. In fact, the radar would both identify the "target" vehicle when we first approach it, and then be the main sensor in the speed regulation loop in the Advanced Cruise Control (ACC) system, as we maintained our following distance to the slow moving vehicle in front.

A third use of radar, also related to steering, has been in following a specially designed radar stripe/tape placed on the roadway. The stripe designed specifically for a given radar frequency and incidence angle, would provide a "bright" reflection back to the antennas on the car illuminating it. The concept of a *cooperative target* is important here, and should continue to be considered as we design the ITS-friendly roadways and vehicles of the future.

A fourth application of radar has again been looking either ahead or sideways from a vehicle, and detecting the existence of specific targets. The targets could be obstacles on the roadway, bridges or posts to identify, or slower vehicles that we may pass. Although not essential, if these objects were friendly targets (with either active or passive devices), providing a good return signal, it would help the interrogating vehicle in its task of obstacle avoidance, lane change, highway exit, etc. as the case may be.

Finally, a radar can be used for more than single point detection but for full scene analysis, and certainly this is an active area of research.

We now consider use of communication between vehicles (Figure 1) to transmit real-time local measurements. The most important parameter to transmit here may be vehicle speed, which a following vehicle can use and has an important effect on picking a following distance. (The "following distance" called *headway*, is picked based on time needed to stop if the car ahead brakes. Communication provides less delay than measurement based stopping. Transmitting information on braking, steering or even road friction can also be considered. All of this type of information can indeed be used and as far as vehicular communication goes, have important implications on Quality of Service (QoS) issues.

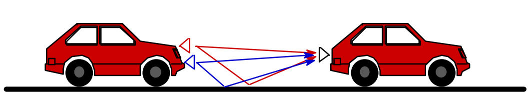

Figure 1. Car-to-car communication

Traffic Related Wireless Technology:

We distinguish this class of usage in terms of higher level decision making and type of activity, from the previous class. Thus, within this class we are no longer considering any vehicle related general measurement activity beyond detection triggered action, but simply information leading to higher levels of driving decisions. We will also consider information about the vehicle being provided to the infrastructure. We can thus analyze two types of applications:

1. Infrastructure based

Vehicle detection, starting with loop-detectors, a wireless technology which certainly predates any talk of "ITS", has evolved to cover many new techniques and technologies. Thus passing vehicles can be counted, their speed sensed or calculated, and individual vehicles can be detected at prespecified locations.

The information obtained can be used for statistical purposes, for adjusting traffic flow (through traffic lights, or directives to vehicles) or for operations to affect individual vehicles (e.g. bus based traffic lights, ticket/toll card dispensing, parking lot direction).

2. Vehicle based

There are a number of examples of ITS applications using both infrastructure and vehicle based technologies. Automated toll collection, automated data verification for trucks, GPS based fleet management (admittedly using infrastructure which is not ITS-dedicated, but infrastructure nevertheless) all exist. Many applications are in the development and testing stages, or have been verified in brief field runs. One could count vehicles whose speed limit can be imposed from the infrastructure, intersections providing cross-traffic information to cars, infrastructure based pedestrian detection for warning vehicles, backup warnings, area-wide road friction detection.

Passenger Related Wireless Technology:

From the publics viewpoint, the most visible applications of wireless technologies to ITS is in the area related to passengers. As in the case of Traffic Related Wireless Technologies, this class is also bi-directional. That is, we are concerned with both providing information to passengers (weather information, traffic information, general news) which may be wide-area, or quite local; or we may want a certain amount of interaction (web access, routing inquiries, local food/hotel/fuel inquiries, and access to specialized services ranging from banking to reaching a baby sitter,).

Undoubtedly this class of technology usage will develop further, and pushed the most by public demand. The utilization of *software radio systems* by vehicle manufacturers, and accommodation of aids to connectivity such as Bluetooth, will be enabling technologies pushing different applications.

In the remainder of this presentation we shall briefly summarize some of the related ITS projects that researchers at the Ohio State University (OSU) have been involved in during the last five years.

Research Example from The Ohio State University: The Microwave "Patch" Reflector

The goal of work described here is to develop an inexpensive, flat, license-plate size radar reflector (a "patch") that can be attached to the rear of a fleet vehicle to serve as a distinctive, stable aiming point for an interrogating radar. To satisfy this goal, radar back-scattering from the patch must be consistently strong over all expected angles of the incoming signal. Also, the radar echo must be distinctive so that it can be recognized in the presence of other strong echoes.

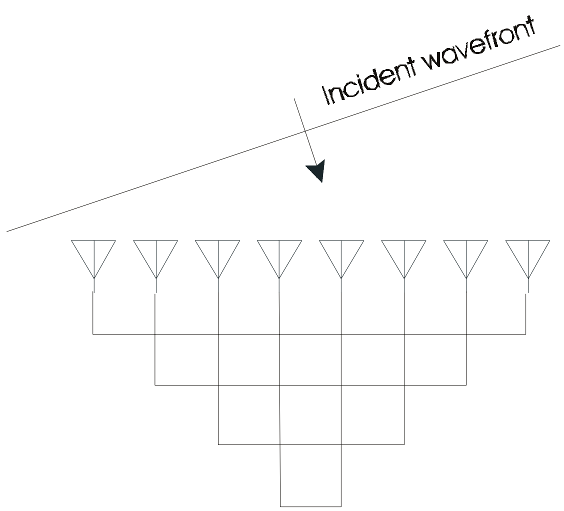

Figure 2. Basis of operation for a Van Atta array.

To achieve this goal we selected a Van Atta reflector approach. The principle of operation is illustrated for a linear array in Figure 2. An array of equi-spaced antenna elements is connected pair-wise by lines of equal time delay. An incident plane wave induces a current in each array element. This current is transmitted to the complementary element, resulting in a re-radiated phase front in the back-scattered direction. The Van Atta concept is inherently wideband, and by selecting suitable antenna elements one can achieve a large echo area with wide bandwidth.

A two-phase development approach was used in this work. In the first phase, we tested the radiating elements to be used. A linear Van Atta array of 16 elements was implemented using thin-wire dipoles on a copper-backed dielectric substrate. A design frequency of 11 GHz was selected. The inter-element connections were made using semi-rigid coax lines of identical length attached to the dipoles from behind the conducting back plane. The radar cross section (RCS) of this model was measured in the OSU-ESL Compact Radar Range. The results of this portion of the study were favorable, with a response variation of no more than 5 dB over an angular range of $\pm 40°$. End-loading the dipoles with capacitive elements was found to increase their efficiency and bandwidth beyond 1 GHz. The efficiency of the design was further improved by careful construction and attention to element uniformity.

In the second phase of our effort we designed a compact stripline version of the feed network to achieve a planar geometry. Once again, the linear Van Atta array configuration was used, but to increase the RCS of the array we elected to use four co-phased antenna elements per feed line. The resulting feed structure (see Figure 2) has two major features. The first is the corporate power divider/combiner that supplies each of the four co-phased elements. Impedance matching and mitering of bends in the traces were used to improve the transfer impedance of the network. Theoretical and numerical studies of the feed based on both transmission line models and finite difference time domain (FDTD) simulations were of limited use in qualitative predictions of the feed's behavior, but lent insight into its operation.

The second feature of the feed structure is the transmission lines (striplines) that connect complementary antenna elements. To avoid the line crossovers shown in Figure 3, a multi-layer design was necessary. Four distinct layers of dielectric are required as shown in Figure 4. The first and third layers are RT/Duroid 6002 (copper-backed Teflon of thickness 30 mils and relative permittivity 2.94). The second layer is a Duroid sheet of the same thickness and dielectric constant but without copper backing. This second sheet contains the trombone-shaped feed lines, with the long parallel segments on one side and the connecting segments on the opposite side. Connections between the layers are performed by soldering with care to avoid creating solder "bumps" that would prevent good contact between adjacent layers. These first three layers comprise a stripline transmission line, which is bounded above and below by conducting ground planes.

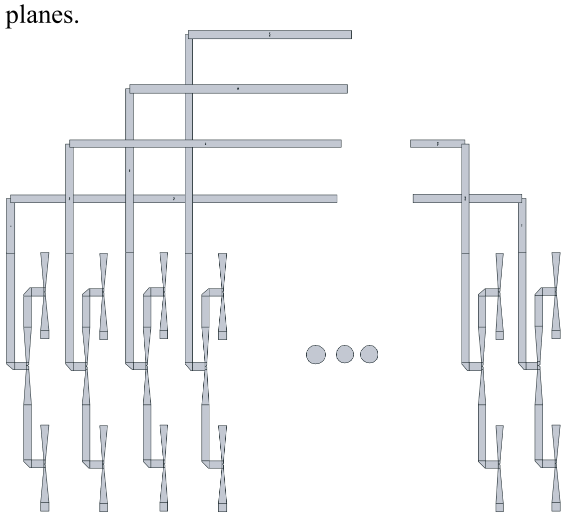

Figure 3. A multi-layer stripline feed structure for a 4×16 planar Van Atta array.

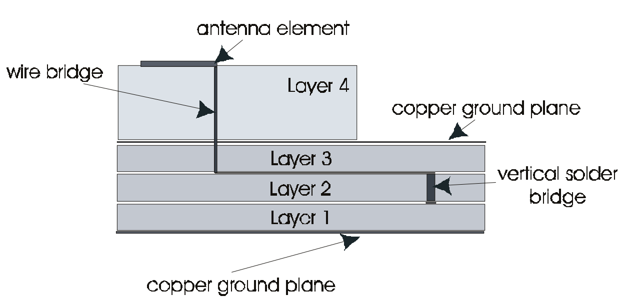

Figure 4. Layers used in the stripline Van Atta array

Multi-layer microstrip circuits are challenging because of difficulties in their analysis and fabrication. In the course of our work we investigated several troublesome aspects of this design. In particular, the impedance discontinuity produced by the vertical jump transition in the second layer was studied by constructing a single transition in a stripline and measuring the *S* parameters of the resulting two-port device. We discovered that very low insertion loss could be obtained by using specific materials and construction practices.

In a further effort to make the antenna signature more distinctive, we employed depolarizing radiating elements. By tilting the elements at 45° with respect to the incident polarization, the antenna can be made to backscatter strongly in the orthogonal polarization. Since single-scattering flat surfaces like those found on automobiles tend not to depolarize, the resulting patch return is more easily detected in the presence of vehicle and roadside clutter.

Our laboratory tests indicate that the antenna described here provides good performance over a large range of angles. Field tests of radar-based vehicle convoying using these antennas have been successfully performed at the TRC test tracks in Marysville, Ohio.

The patch is a microwave analog of the optical retro-reflector and, hence, it has applications in a variety of fields. Such devices could be used to provide obstacle warning markers for road vehicles, marine vehicles, and aircraft. Because of its depolarizing qualities, the patch can be used to locate a desired target in an otherwise cluttered environment. For example, a patch at a fixed point on the ground could be used to improve the operation of radar altimeters in aircraft and radar-based detection of landmarks or downed aircraft.

Research Example from The Ohio State University: The Radar Reflective Stripe

One of the unique ITS related technologies developed at OSU was a radar reflective stripe. The stripe, developed 1994 onwards, and used in the 1997 AHS Technology Demonstration in San Diego, was utilized for lane keeping. The concept, demonstrated effectively on three Honda Accords outfitted for automated driving, used OSU's control algorithms to follow the stripe placed in the middle of the lane (Fig. 4).

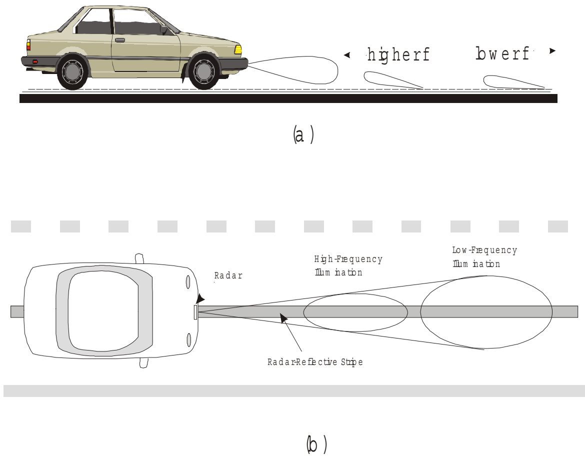

Figure 5. The radar-reflective stripe concept, side view (a) and top view (b)

For reliable, cost-effective, radar-based vehicle navigation, the stripe should exhibit the following characteristics: (1) it should produce strong backscattering at an elevation angle determined by the radar-roadbed geometry; (2) the backscattered signal should be as independent of azimuth angle as possible; (3) to avoid interference with other radar operations (e.g., obstacle detection), the stripe's frequency response should be relatively narrowband; (4) the stripe's response should be tolerant of variations in highway conditions including roadbed composition and precipitation; (5) it should be inexpensive to manufacture; and (6) it should be convenient to install.

The stripe was manufactured for OSU by the 3M Corporation. After discussions with 3M, it was determined that the cost and installation objectives could be met by using manufacturing techniques now used for conventional roadway marking stripes. Such stripes consist of a thin aluminum foil laminated between a lower adhesive layer and an overlying colored layer. The radar reflective properties of our stripes derive from slots punched in the aluminum sheet. The stripe is designed for installation over dry concrete, but numerical studies suggest that it will perform acceptably for a variety of roadbeds.

The OSU stripe concept comprises a one dimensional periodic array designed to produce a strong backscattered signal at a specific elevation angle and frequency. As noted above, slot scattering elements are used, which implies that the radar illumination should be vertically polarized. The backscattered return is the result of a grating lobe at a fixed angle with respect to vertical, which is related to the spacing of the periodic surface and the frequency

The frequency-selective nature of a periodic array has several implications. We find that responses from different portions of the stripe contribute at different frequencies as shown in Figure 5. Higher frequencies come from stripe regions closer to the vehicle, and lower frequencies come from more distant regions. The vehicle geometry has implications for the stripe's frequency range. To minimize the impact of radar navigation on vehicle design, it is convenient to locate the radar antennas in the front bumper of the vehicle. For successful vehicle navigation at highway speeds, it is necessary to interrogate the stripe at distances of several meters or more, which leads to near grazing viewing.

The slot pattern for 11 GHz operation, shown in Figure 6, is a linear array of equi-spaced pairs of thin apertures arranged in a broken chevron design.

Several other aspects of the stripe were considered in the design. The azimuth pattern is critical to successful operation. By varying the slot lengths and relative angles we can reduce the stripe's azimuth dependence, leading to improved stripe tracking. Stripe cross section is increased by using longer slots and judiciously chosen angles. Manufacturing problems are reduced by using relatively wide slots and by using a center web (inherent in the broken chevron design) to increase structural strength. Nominally, the stripe will be used on concrete or asphalt roadways. The dielectric properties of the lower medium and of any overlying material must be taken into account in its design.

OSU has also developed a stripe design for operation at 77 GHz. Manufacturing limitations make it impractical to fabricate a scaled copy of the 11 GHz design. Our alternative design employs periodically-spaced rows of wide slots arranged in circular arcs. The circular shape provides a measure of angle invariance for operation at wide azimuth angles

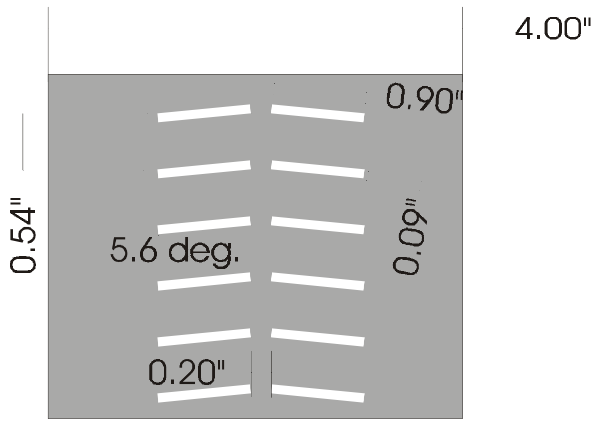

Figure 6. Design for the OSU 11 GHz stripe. Stripe response is essentially independent of direction of vehicle traffic.

The responses of both the 11 GHz and 77 GHz stripe have been confirmed both with numerical models and with experimental tests of stripe samples. Numerical modeling of the stripe response with ordinary radar scattering codes is difficult at near-grazing angles (the angles of greatest concern), because of interaction between the incident field and the lower half space. A numerical model for scattering from the stripe in free space was created using OSU-developed electromagnetic scattering codes. The effects of the roadbed were incorporated a posteriori using an approximate technique. We have of course had more experience validating the 11 GHz stripe.

Research Example from The Ohio State University: The Wireless Network Testbed

The United States National Science Foundation in the last year recognized wireless network research ongoing at OSU by awarding a three year project to build a wireless testbed. The goal of the testbed is to bring together theoretical and experimental researchers in an environment where the classic scientific method can be practiced. The foundation of the testbed is the narrowband systems that were developed for ITS applications. This foundation is being formed into a multiple base station wireless network capable of supporting both general (non delay constrained) packet data and real-time remote vehicle tracking using data from a GPS receiver. Updates will be received from the remote unit on a four second interval and the position can be displayed at a location connected to the base station. This testbed will consequently demonstrate a variety of network modes (delay constrained and non-delay constrained). The hardware in the narrowband testbed is all manufactured by commercial companies with special modifications that the OSU team has specified. The software that provide both the physical layer and the network layer functionality are written by researchers at OSU. Having a physical layer testbed has given OSU the ability to look at performing a wide variety of experiments in wireless networking. Additionally new features such a space-time or turbo coding will be added in the near future.

In addition to the narrowband system OSU has been chartered to build a wideband system of similar capability. This wideband system's goal is to support experimental research in wideband multi-media applications (voice, video, data) at both the physical layer (radio receivers) and the network layer. This nascent wideband system is currently being specified with the equipment manufacturers but the goal is to have a similar testbed as the narrowband system. The hardware will be very flexible in it's performance. The hardware will support a wide variety of bandwidth, center frequencies (though we will likely operate in the 2.4GHz ISM band primarily), number of antennas, and data rates all of which will be software controlled. The goal is to use the most advanced technology and research results in wideband code division multiple access (CDMA) to formulate the testbed architecture.

Other ongoing work in ITS wireless communications at OSU are the following:

- Narrowband telemetry applications
  - 220MHz channels were given to the ITS program for nationwide usage.
  - OSU has developed a software radio testbed for this frequency band.
- Vehicle-to-Vehicle Communications
  - Looking at optimizing ad hoc communications between vehicles on the roadway.
- OSU has an FCC license to transmit and operate a base station in the Narrowband Radio Services Spectrum (220-222MHz)

- Work has been ongoing at OSU to develop modems for this band under funding from the FHWA and NSF
- The OSU narrowband modem has been deployed by the INDOT
  – Pan/Tilt/Zoom control of a video camera in an advanced traffic management system
  – Joint work with OSU software and a San Diego wireless company building the hardware.
- Aiming to start an FHWA development contract to shrink the size and add functionality.
- Channel modeling and transmission optimization
  – Space-time coding
  – Multiple access signaling

Figure 7. The OSU narrowband modem (bottom) and the video camera controller (top).

Research Example from The Ohio State University: SAR and ISAR for Automotive Applications

The objectives of this ongoing project are to understand vehicle/infrastructure scattering phenomena that affect automotive radar in order to both improve vehicle detection and to reduce false targets. We will also be identifying radar improvements that require no new hardware.

To this end we have worked on characterization issues by instrumenting a vehicle radar and measuring scattering from reference targets. We have also worked on algorithm development by creating software for forming SAR and ISAR images from the vehicle radar data. We are presently continuing our investigations in controlled tests.

Real Aperture Radar Imaging: We use narrow beams and wide bandwidth to interrogate local regions on target. Multiple beams (or single scanned beam) is required for this operation. Down-range resolution is determined by bandwidth. Cross-range resolution is also determined by beamwidth and degrades as range increases. The signature varies strongly with angle (coherent superposition of scattered returns).

Synthetic Aperture Radar Imaging: Observation over a range of angles with a broad antenna beam can replace multiple narrow beams. Range in viewing angles determines cross-range resolution and bandwidth determines down-range resolution. Reduced sensitivity to view angle (return is integrated over angle) can be pointed out. Changes in viewing angle are produced in two ways: cross-range motion of radar (SAR) and rotating target (ISAR).

In automotive ISAR, vehicles undergo apparent rotation when entering/leaving curves, changing lanes, being overtaken, etc. At 77 GHz only 0.4º of rotation is required to form ISAR images with 30 cm cross-range resolution. Only objects rotating at same rate form coherent image (automatic grouping of scattering centers on same vehicle). Cross-range resolution improves as headway decreases (positive relation to increasing safety concerns)

System Considerations: Benefits of SAR or ISAR processing are:

- Improved cross-range resolution
  → *Not degraded by increasing range*
  → *Potential for better rejection of false targets*
- Reduced signature variability with angle
  → *SAR and ISAR integrate returns over angle*
  → *Avoids "wandering" scattering centers, target breakup*
- Faster updates possible
  → *No beam scanning*
- Simpler antenna design
  → *Can use single wide beam: no mechanical or electrical scanning required*

Drawbacks can be listed as the following:

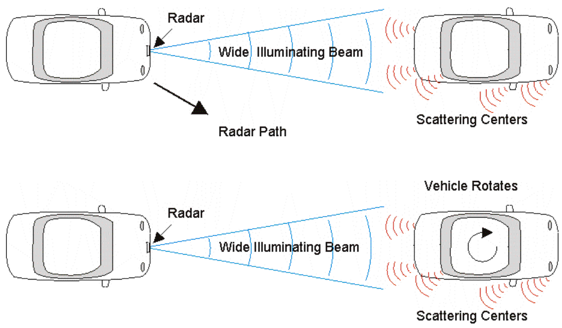

Figure 8. SAR and ISAR imaging

- Increased radar power

  → *Reduced antenna gain will increase radar power requirements. (Alternatively, use narrow scanned beams to paint target.)*

  → *Hybrid operation – combine both real and synthetic aperture functions?*
- Processing requirements increased
  → *Quantitative assessment TBD*

Conclusions:

In this presentation we have first listed and briefly analyzed the different areas wireless technologies contribute to ITS. We then considered a set of ITS Projects at the Ohio State University in the Wireless area. The Projects were on different aspects of radar usage and radar reflective surface design and communication systems. This is by no means an exhaustive coverage (even for OSU) and indeed wireless technologies provide a rich research area contributing to the advancement of ITS.