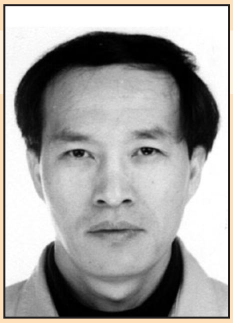

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Driving into Intelligent Spaces with Pervasive Communications

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Recent advances in digital modulation and transmission, signal processing, wireless access protocols, and IC technology have spawned many intelligent devices and objects. Seamless communications among such devices and possible processing centers can transform ordinary environments into intelligent spaces.[1] The close coupling between physical and virtual spaces distinguishes intelligent spaces from virtual reality environments. Other attributes of intelligent spaces include

- system perception, cognition, analysis, reasoning, and prediction of users' status and surroundings. Situation awareness is the most fundamental form of such capabilities; the system should be aware of any information it can use to characterize an entity's situation—in other words, its context.
- high adaptivity to inhabitants' activities. This attribute contrasts with conventional computing environments centered at computers.

As the information age advances, intelligent spaces will become more common applications in smart homes, workplaces, classrooms, and hospitals. We also envision vehicles and a transportation infrastructure that will depend on *intelligent transportation spaces*.[2] ITSPs keep vehicles connected with their occupants and, as figure 1 shows, with other vehicles and systems that offer traffic, route, weather, and entertainment resources for safe, efficient, and enjoyable travel.

Intelligent transportation spaces

The potential benefits of intelligent transportation systems (ITSs) include driving safety, transport efficiency, and comfort that accrue from increased traffic information, reduced driving loads, and improved route management. ITSPs integrate various ITSs to enhance their autonomous and cooperative functionality. Joo-Hoo Lee and his colleagues at the University of Tokyo and Toshiba describe a primitive but interesting example using *autonomous guiding vehicles,*[3] which many factories deploy AGVs for unmanned transportation. AGVs require some guiding mechanism. One method is to build guiding rails with special tapes, but this approach requires reconstruction of the guiding rails whenever a layout change occurs—which can be frequent in, for example, a warehouse. In addition, AGVs are equipped with range sensors to detect obstacles, especially human workers in the same environment. When multiple AGVs are present, the range sensors can induce interference.

An intelligent space could help resolve both these issues. Instead of making AGVs increasingly smart and complicated, you could try making the surrounding environment smarter. Lee et al., for example, mounted range and change sensors to warehouse walls and ceilings.[3] The sensor system shares the collected information with the AGVs. If the system also distributes routing information from some mounted processors, the guiding rails become unnecessary. As the environment becomes more flexible, AGV costs go down. The environment is more complicated, but its costs are shared by all the AGVs.

The mounted cooperative sensors in this example establish an ITSP, although we expect future ITSPs to be far more intelligent and comprehensive. Most research on intelligent spaces focuses on smart rooms. Partitioning ITSPs into intravehicle and intervehicle intelligent spaces can help delineate their differences from smart rooms.

Intravehicle intelligent spaces

Inside the vehicle, the intraVIS environment is a human-centered, closed space with well-defined boundaries surrounding relatively static objects—a setup reminiscent of smart rooms. In fact, many smart-room functionalities carry over with slight or no modification. Examples include spoken language interaction, face recognition, speaker identification, and biometric identification.

However, there are some fundamental differences as well. For one, it's easy to augment objects inside the vehicle to make them computational and connectable or, simply put, smart. Most vehicle parts can accommodate embedded sensors and processors. For example, car seats often already

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have pressure sensors that can register and recognize people sitting in the seat. This is generally not true in a residential environment.

Another difference is that people usually stay in a set location during an entire trip. In smart rooms, on the other hand, people move in ways that can require target tracking for multiple persons. Likewise, the activities in smart rooms cover a broader spread—anything from ironing to surgery, whereas the intraVIS activities usually fall into a few predictable categories: automatic cruise control, communication within the vehicle or with the outside world via the vehicle, and entertainment requests. The large space of smart rooms sometimes forces occupants to wear bulky sensing or communicating devices, such as wireless microphones for speech interactions. This is typically not an intraVIS problem.

The transportation domain has already taken steps toward intraVISs. Examples are hands-free entertainment and communications systems, wireless tire-pressure-monitoring systems, and intelligent systems for vehicle-motion control.[4]

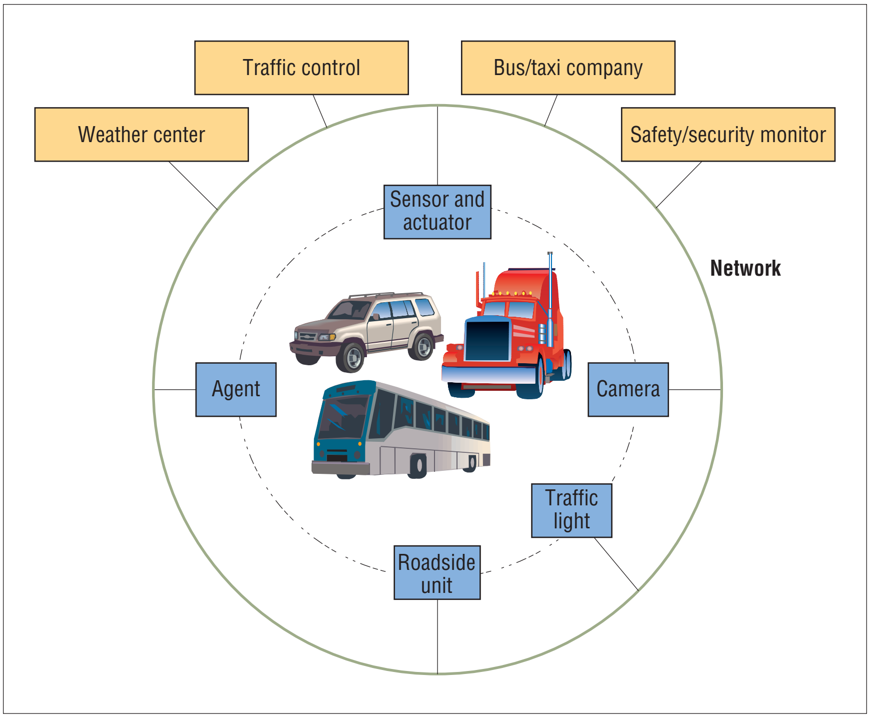

Figure 1. Intelligent transportation spaces.

Intervehicle intelligent space

InterVIS encompasses the computations, communications, and interactions among vehicles and with roadside units, such as toll plazas. These spaces lack well-defined boundaries, and the relative speed differences between the vehicles and roadside units can be very high. In addition, space components and interconnection topologies can change rapidly. Clearly, these features call for design principles drastically different from those in smart rooms and interVISs.

The forecasted functionalities of interVISs include vehicle-to-vehicle (V2V) communications, vehicle-to-roadside (V2R) communications, electronic-toll-collection systems, advanced cruise-assist highway systems, danger alert, and automatic machine activation in highly circumscribed conditions. In addition, multimedia traffic communication services, including general, map, and entertainment information, are also desirable as a future developmental form.

Recent advances toward interVISs include the transport-information-monitoring environment, launched in Cambridge as a framework for collaborative research and for application and deployment of traffic-information monitoring, processing, and distribution. Another example is a proposal for *robotic safety barrels* to replace traditional barrels for certain highway work zones. Equipped with communications and robotic capabilities, the RSBs could self-deploy and self-retrieve to eliminate the danger associated with manual placement. In addition, remote control could reconfigure RSB positions according to work-zone changes. Researchers have also developed traffic-flow forecasting algorithms[5] and agent-based control for networked traffic management systems.[6]

The two-level structure is convenient for thinking about ITSPs, but it doesn't really separate the intra- and interVISs. For example, automatic-cruise-control functionalities such as collision avoidance and route planning rely not only on the intravehicle ITSP and communications but also on the information exchange with neighboring vehicles and roadside units. Likewise, alerting a driver takes the collaborative operations of both inter- and intraVISs.

ITSP enabling technologies

Progress toward pervasive computing environments is already evident in the broad distribution of many computers of different sizes and functions. At this step, we expect advances in communications to facilitate the interconnections among these distributed devices and eventually turn the computing environments into intelligent spaces. Indeed, intelligent spaces are inseparable from communications.

Although wireline communications might enable some ITSP requirements, such as interVIS communications, the inherent mobility, flexibility, and scalability of wireless communications clearly make them critical. Enabling technologies in this area include an array of wireless solutions.

ISM bands

In the US, the industrial, scientific, and medical bands refer to the 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz frequencies. The Federal Communications Commission (FCC) originally reserved the ISM bands for noncommercial use of radio-frequency electromagnetic fields, but many commercial uses of them have emerged, including cordless phones, wireless local area networks, and Bluetooth applications.

Several automobile manufacturers use the ISM bands for built-in, hands-free voice communications. Bluetooth car kits include hands-free headsets, speakers, and

CD and MP3 players with built-in transceivers. Recently, a vehicular communications system used Bluetooth-enabled cameras to collect and disseminate road congestion and accident information. Researchers also compared various sensor-network technologies in the ISM bands for the traffic application as well as for intraVIS applications.[7]

DSRC bands

In 1999, the FCC allocated intelligent transportation systems 75 MHz of dedicated spectrum (5.850–5.925 GHz), referred to as dedicated short-range communications bands. The American Society for Testing and Material is leading the North American development of DSRC standards. ASTM's E17.51 working group has selected OFDM (orthogonal frequency-division multiplexing) as the basis for DSRC air interface and a slightly modified IEEE 802.11a as its DSRC E2213-02 standard for telecommunications and information exchange between roadside and vehicle systems. The FCC adopted DSRC service rules in 2003.

More recently, the IEEE 802.11p task group started a standardization process on the DSRC band to define Wi-Fi enhancements required to support intelligent transportation space applications. Also referred to as WAVE (wireless access for the vehicular environment), the IEEE 802.11p activity addresses data exchange between high-speed vehicles and between these vehicles and the roadside infrastructure.

UWB radio

The FCC defines "ultra-wideband" as transmission systems with instantaneous spectral occupancy in excess of 500 MHz or a fractional bandwidth of at least 20 percent. In 2002, the FCC released a spectral mask allowing operation of low-power UWB radios over a bandwidth up to 7.5 GHz. This huge bandwidth supports high-rate communications (up to 480 Mbps) over a short range (10–15 meters) even at very low power levels prescribed by the FCC.

The IEEE 802.15 working group is standardizing UWB wireless radios for both high-rate wireless personal area networks and low-rate sensor networks. Developers can potentially expand these networks to accommodate ITSP needs. Similar to the frequency-reuse principle of wireless cellular architectures, low-power short-range UWB communications can potentially provide high spatial capacity in terms of bits per second per square meter.

In addition, UWB radios have several unique advantages. These include enhanced capability to penetrate obstacles, localization precision down to the centimeter level, potentially very high data rates and high user capacity, and potentially small device size and processing power via carrier-free operations. These advantages open the door for an unprecedented number of low-power, position-critical, and bandwidth-demanding applications.[8]

Of course, UWB is not without critics. A key source of criticism comes from claims that UWB transmission could interfere with ISM and DSRC bands. Researchers are pursuing ways to minimize the interference among UWB communicators and with coexisting legacy systems.[8] The FCC is also investigating this issue, but it still plans to open up more spectrum for UWB commercial applications. Given the lack of fees for UWB spectrum usage, commercial applications might be unstoppable.

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MAC protocols

The media-access-control protocol for IEEE 802.11 was originally developed for wireless local area networks. The protocol is based on the CSMA/CA (carrier sense multiple access with collision avoidance) protocol. In an ad hoc network with no access point, the *distributed-coordination function* is the fundamental mechanism for media access. DCF allows an initial exchange of control packets that can greatly reduce collisions in a multihop network.[9] When an access point is available, the *point-coordination function* also supports collision-free media access; PCF is a centralized MAC protocol.

DSRC applications can operate in an ad hoc or infrastructure mode. In the ad hoc mode, distributed mobile multihop networking lets vehicles in a fleet communicate peer-to-peer directly (V2V); in an infrastructure mode, a centralized mobile one-hop network supports communication between vehicle and fixed roadside hubs (V2R). In the V2V scenario, the network's multihops are the major performance concern; in V2R, the vehicle's speed with respect to the roadside units is the major issue affecting MAC performance. The 802.11 MAC layer design requires enhancements to open interfaces for integrating solutions that could address ITSP issues such as the multirate communications, the shortened connection time and frequency updating of stations in the coverage area, as well as the increased data rates due to the shortened connection time.[9]

In safety-critical V2V/V2R communications, quality of service in terms of bounded latency and reserved bandwidth is important. In the PCF mode of IEEE 802.11, HiperLAN, and Bluetooth, the access point uses a centralized approach to achieve bounded latency.[10] However, V2V applications call for a distributed approach that's robust against single-node failure and can support flexible network topologies. For this purpose, researchers developed the *wireless token ring protocol*.[10] WTRP improves MAC efficiency by reducing the number of retransmissions due to collisions. It's also more fair in the sense that all nodes get the same time share of the channel. These features make WTRP suitable to scenarios requiring the rapid establishment of a communications infrastructure with QoS guarantees. Both the Automated Highway System program[11] and the Berkeley Aerobot project (http://robotics.eecs.berkeley.edu/bear) deployed it.

Other technologies that facilitate intelligent transportation spaces include vehicular telematics, vehicular radars, and RFID. Among the applications these technologies enable are mayday systems, stolen-vehicle tracking, automatic route guidance and travel information, intelligent near-collision avoidance, tire-pressure monitoring, vehicle entry and security systems, electronic toll collection, automatic vehicle identification, and real-time location systems.

The work to advance all these technologies calls for multidisciplinary R&D efforts. We hope this overview will help advance the state of the art in ITSP.

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