White Paper: Inform the Five Year Strategic Plan for the Federal Networking and Information Technology Research & Development

Mobility in modern society comes at a high cost. Traffic injuries and deaths, congestion-induced delays, and pollution incur enormous costs worldwide. For example, in the U.S. traffic congestion resulted in an estimated 3.7 billion hours of delay and 2.3 billion gallons of wasted fuel in 85 major urban areas in 2003, yielding an estimated cost of $65 billion [1]. Over 6 million crashes occur each year resulting in over 40,000 fatalities and an estimated $150 billion in economic loss [2]. Vehicle emissions are the leading cause of health-related air pollution. Travel demand is expected to rise by 50% in the U.S. to reach more than 4 trillion vehicle-miles traveled by 2020 [3]. Natural and man-made disasters can create gridlock, impeding emergency vehicles and personnel and potentially costing lives. Similarly, transportation has created major societal problems in Europe and developing countries such as China and India. Even modest improvements of only a few percent can result in billions of dollars in savings each year.

Intelligent Transportation Systems (ITS) exploit networking and information technology to alleviate these concerns, and are now widespread. However, ITS deployments have reached an inflection point, and are entering a new era. Costs associated with deploying and maintaining infrastructure, technological advances in sensing and wireless communications, and the lure of increased capability, coverage, and efficiencies are driving ITS toward systems that feature widespread exploitation of in-vehicle sensing, vehicle-to-roadside and potentially vehicle-to-vehicle communication [4-9]. For example, the USDOT's Vehicle-Infrastructure Integration (VII) initiative is a public-private partnership where wireless communication devices are being installed in the nation's vehicle fleet and roadside infrastructure [9-13]. It is estimated that 10% of the nation's vehicle fleet may be instrumented within two years of the commitment to deploy the system [11], resulting in a major shift in the operation of transportation systems in a relatively short period of time. Networking and information technology deployments utilizing in-vehicle and roadside computing and communications will need to be integrated with more traditional infrastructures such as adaptive control devices, embedded sensors, and traffic management.

As such deployments become widespread travelers will depend upon networking and information technology more and more in every day use. This technology will only become visible to travelers when it fails to operate properly. The consequences of such failures will be high, resulting in severe economic loss, and in conditions such as emergencies, failures could result in loss of life. Such deployment must have several key attributes:

- *Resiliency* - Future transportation systems must be resilient, reliable, and robust to failures; their supporting networking and information technology built over large-scale transportation cyberinfrastructures must share these features, particularly under communication failures resulting from natural disasters and attacks.
- *Adaptive and transparent* - The system must be able to automatically adapt to unexpected events such as crashes and roadway incidents. It must be transparent and provide services to travelers without creating driver distractions.
- *Scalability* - such systems must be implementable in rural, suburban, and urban settings, with population ranges from a few thousand to millions. Large wireless networks must provide effective communication services to hundreds of thousands of network nodes.

The realization of effective systems presents enormous technical challenges. Over a large urban area, such a system will involve the interaction of potentially millions of nodes, including vehicles, control and detection devices, and management services. Under emergency scenarios, such a system can be envisioned to reach the individual person level, requiring near-instant communication interaction with hundreds of thousands to millions of individuals in real time. In the future, the ability to manage the transportation system under normal and emergency conditions will not be constrained by the availability of data. The true limitations concern data management, processing, and networking. Deployed systems will be composed of a heterogeneous collection of in-vehicle, roadside, and traditional (e.g., TMC/EMC-based servers) computation and sensor nodes that must analyze current system states, predict future states, and rapidly adapt to unexpected disruptive events on short time scales.

Federal Networking and Information Technology Research and Development must support the study and development of such systems as well as rapid commercialization if they are to achieve their fullest potential. Creating and sustaining this new paradigm presents many major challenges. For instance, what will be the form of the system architecture? Can a resilient system be ensured? How will system recovery be implemented? Can the system have sufficient redundancies while remaining efficient operation? Will the system continue to function under the added stress of emergency events (e.g. natural or manmade)? What vulnerabilities are introduced into the transportation system with increasing automation? Can a communications system be designed that achieves the reliability required to operate such a system? How should the massive amounts of real-time data produced in such a system be processed and mined to extract useful information in a timely fashion? Can approaches to information sharing and data anonymization be found that maintain acceptable levels of privacy among travelers while still providing adequate information to effectively manage the transportation infrastructure? What business models are appropriate in realizing public-private partnerships that meet the requirements of government, industry, and the public at large?

The Federal Networking and Information Technology Research and Development program must support the fundamental research necessary to test and model such systems. For instance, simulation models that capture *both* the transportation and communication infrastructures and their interdependencies are essential to answer questions such as these. These models must be able to capture emerging behaviors of such deployments on a large-scale, e.g., a large metropolitan area. So-called “urban canyons” create major challenges for wireless communication, and cross-layer protocol interactions must be captured to accurately characterize Quality of Service (QoS) properties of the network infrastructure, which ultimately affect the overall behavior of the deployment. This necessitates detailed modeling of the network, including accurate capture of the effects of physical terrain. Such simulations must incorporate detailed models of individual vehicle movement and behaviors, operating in conjunction with detailed, accurate models of the communication infrastructure.

These research challenges are inherently multidisciplinary. Technology development efforts must combine research from transportation, wireless communication, computer science, statistics, operations research, and modeling and simulation, among others. Environmental engineering expertise is needed to help ensure the creation of sustainable infrastructures. Research in the social sciences is required to address issues such privacy, and public policy issues similarly plays a critical role that must be considered in the deployment of such systems.

Effective research and development programs fundamentally require successful multi-agency collaboration. Both in day-to-day and under emergency conditions federal, state, local, and private agencies must be seamlessly networked. Different aspects of the transportation network fall under the purview of each agency, often with several agencies having some shared responsibility over a portion of the system. Another crucial feature of the Federal Networking and Information Technology Research & Development program should be meeting the challenges of integrating the information technology systems of the disparate agencies responsible for operating the transportation system and developing a means to foster and maintain this integration over time.

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