RESEARCH NOTES
September 2007

Analytical Studies of Peer-to-Peer (P2P) Information Propagation

(ATMS TESTBED PHASE III FINAL REPORT)

Why Was This Research Undertaken?

The rapid advance in available information technology, especially, the development of wireless communication technologies, now makes feasible the exploration of traffic information systems that decentralize the tasks of collecting and disseminating traffic information. Compared to centralized ATIS systems, a decentralized system based on Inter-Vehicle Communication (IVC) offers some significant advantages: (1) the IVC components of the system require no capital investment on the part of the transportation agencies, and can evolve to a full system gradually, once a threshold market penetration is achieved; (2) both the monetary and labor costs to build and operate the system are directly distributed to the users of the system; (3) the system is much more resilient to disruption, particularly in the event of disasters, when communications, management, and control are most important; (4) the system can be anchored to the Internet as a platform for additional applications.

For more in depth discussion and technical analysis, refer to the testbed technical reports TTR3-01 and TTR3-02.

What was done?

In this project, we developed a novel analysis framework for the performance of inter-vehicle communication in a traffic stream. With the assumption that information propagation is instantaneous compared to vehicle movements, we consider the probability of success for information to propagate beyond a location. Most-forward-within-range communication chains and transmission cells were defined, measurement probabilities were modeled regressively, and examples were studied for different traffic scenarios, transmission ranges, and market penetration rates. This mathematical model was found to be consistent with simulation-based studies.

In an effort to understand the structure of the complicated P2P system, we first make an assumption that information propagation through IVC is instantaneous. This simplification is based on the observation that vehicles' movements are inconsequential during the short transmission time of a message (in the order of one-tenth second). Therefore, the effect of traffic dynamics is omitted, reasonably, but the distribution pattern of vehicles caused by road geometry and car-following rules are included.

We started by defining "most forwarded within range" communication chains and splitting a traffic stream into a number of cells based on the transmission range of wireless units. Then by considering the relationship between communication chains and transmission cells, we obtain two basic components for constructing an arbitrary communication chain. With the understanding of the structure of information propagation, we are able to derive a regressive model for computing the success rate for information to travel beyond a certain point.

What can be concluded from the Research?

With this model, the user can evaluate the performance of certain wireless communication units for different market penetration rates and traffic patterns.

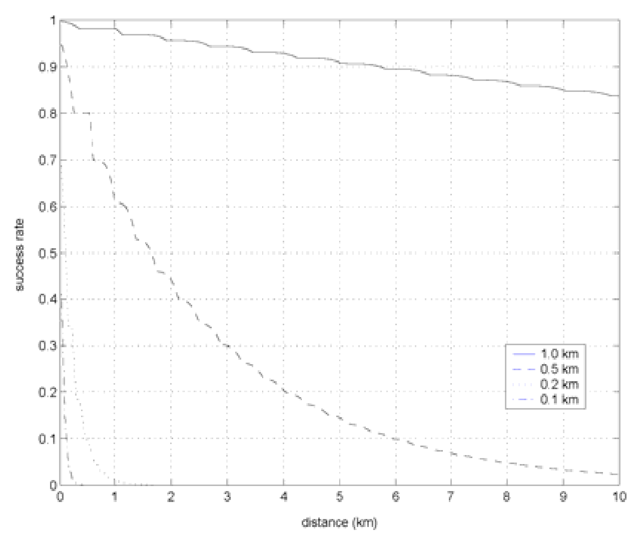

Figure 1: Success rates vs. transmission ranges: penetration rate = 10% and four-lane road with density of 56 veh/km

For example, we evaluated the influence of different communication ranges on the information propagation as shown in Figure 1. As expected, longer transmission ranges yield better propagation results. The results in this figure are consistent in magnitude with those in the literature by simulation studies. This further argues for the assumption of instantaneous information propagation.

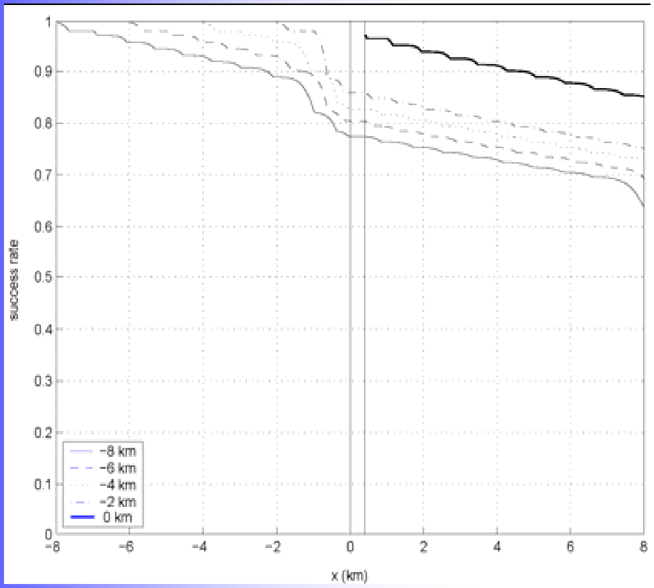

Figure 2: Success rates of information propagation for different locations of information so

We also applied this model to study the impact of a gap in a traffic stream on information propagation. As shown in Figure 2, a gap at [0, 0.4 km] can seriously deteriorate the success rate (by more than 10 percentiles) for different locations of information sources.

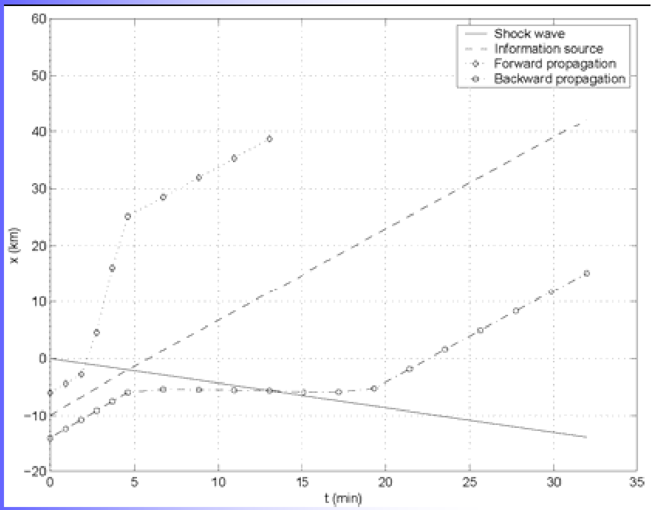

Figure 3: Information progress with 95% success rate in a shock wave

In Figure 3, we show the influence of a shock wave on information propagation. Here, the information source vehicle runs into a congestion shock wave and slows down (from 104 km/h to 97 km/h). For a number of time instants, we consider the propagation distances of 95% success rate in both forward and backward directions.

We can clearly see the bending effect of traffic density change on information propagation. This example shows that a small change in traffic density (60 veh/km vs 80 veh/km) can have substantial consequence on information propagation distances (4 km vs 27.1 km).

What do the Researchers recommend?

This project demonstrated the effectiveness of the mathematical model for evaluating the performance of IVC in a traffic stream. Use of this model can significantly reduce the time required for evaluating the influence of communication ranges, market penetration rates, and traffic pattern on the success rate of information propagation. The model can be used for estimation of the performance of Autonet system.

Continued efforts are needed to extend this analysis framework for studying other important issues related to IVC systems, such as communication capacity, and the impact of road network topology.

Implementation Strategies

Ramp metering control involves balancing the interests of local (arterial) and through (freeway) traffic, and thus its applicability, onsite deployment and operation continue to face political challenges that call for the cooperation of related parties. Because of the complexity of these coordinated ramp metering systems, their successful

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