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アドホック通信製品における性能評価実験と課題および車両間通信に向けて新しいアーキテクチャの提案

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あらまし 車両間通信並びにアドホックネットワークは、他の手段ではなし得ない安全運転支援あるいは多くの ITS 応用を実現可能とする有望な新技術である。自動車におけるアドホックネットワークは、MANET フレームワークにおける議論と比べいくつかの根本的に異なる要求や特徴をもつ。本論文では、現在入手可能な製品について、それら性能や能力の現状を調査した。予備実験の結果によると、いずれの製品もいくつかの望ましい特徴は示すものの、自動車への応用における厳しい要求をすべて満たすシステムは存在しなかった。次に、課題となる領域の定性的な分析を行い、車両間通信へのグルーピング構造の導入による改善方法を提案する。

キーワード：アドホックネットワーク、車両間通信

Ad-hoc Vehicle-to-Vehicle Communications: Experimental Performance, Problems and a New Architecture

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Abstract Intervehicle communications and ad hoc networks are promising new technologies to enable safety assistance and several other ITS applications that are not feasible otherwise. Vehicular ad hoc networks exhibit some fundamentally different requirements and characteristics than those discussed within the MANET framework. In this paper we investigate the current status of the off-the-shelf products to get a glimpse of their performance and capabilities. Our preliminary results show that while each product exhibits some desirable characteristics, none of the tested systems meet all of the stringent requirements of a vehicular application. We then provide a qualitative analysis of what the problem areas are and how they can be improved leading to the proposal of a new grouping scheme for intervehicle communications.
Keywords: ad hoc networks, intervehicle communication

I. INTRODUCTION

Intervehicle communications and ad hoc networks are promising new technologies to enable safety assistance and several other ITS applications that are not feasible otherwise. The idea is to make use of intervehicle communication to relay messages pertaining to road hazards, non-line-of-sight obstacles such as stopped vehicles ahead, and other emergencies, in order to extend the driver view substantially. Intervehicle communication has also the potential to prove useful in future coordinated driving systems.

However, vehicular ad hoc networks exhibit some fundamentally different requirements and characteristics than those discussed within the IETF MANET (Mobile Ad hoc Networks) framework [3]. High speed mobility of the network nodes makes the self-organization of the network an extremely difficult task. Nodes frequently and rapidly joining and leaving an ad hoc network will create enormous processing overhead. High speed mobility also makes the interference and fading problems worse. These concerns have led us to investigate the current status of the off-the-shelf products to get a glimpse of their performance and capabilities.

In this paper, we start by looking at some of the commercially available ad hoc networking products in order to assess the capabilities and limitations of the present technologies from the viewpoint of vehicle-to-vehicle communications and safety assistance applications. We describe experiments and results addressing throughput, communication range, multihopping capability, and connection setup time characteristics of three off-the-shelf products. Our preliminary results show that while each product exhibits some desirable characteristics, none of the tested systems meet all of the stringent requirements of a vehicular application. We then provide a qualitative analysis of what the problem areas are and how they can be improved leading to the proposal of a new grouping scheme for intervehicle communications.

In Section II we briefly introduce these products and describe their features followed by the experimental results obtained. Section III discusses the problem areas with current technologies and Section IV introduces a new architecture for intervehicle ad hoc networks.

II. EXPERIMENTS WITH OFF THE SHELF AD HOC NETWORK PRODUCTS

In this section, we will look at three of the commercially available ad hoc networking products with the goal of assessing their suitability for intervehicle communications. Experiments and their results in this section are described in more detail in [1].

All of the products described in the following were purchased and tested in the USA, manufactured under the FCC regulations. Although some of the USA-based products are becoming gradually available in Japan, those are manufactured according to the Japanese regulations which may result in different performance figures than presented in here.

Recently there have been a flurry of ad hoc and mesh networking product announcements utilizing either IETF MANET protocols or likes of them, mostly based on IEEE 802.11a/b/g wireless media. Some of these products have the capability of operating in moderately mobile environments while some other are not specifically targeted for mobile environments. For example, there are mesh networking products which are quite advantageous in quickly establishing WLANs in broad spaces such as airports without the extra cabling in between the WLAN access points and/or routers.

We selected three of the products (named, A, B, and C) available on the market and performed experiments with them. In [1], we provide a more detailed explanation of these experiments and their results, however we include many of those results here for the sake of completeness.

Product A

Product A combines a proprietary routing algorithm and a proprietary radio over 2.45 GHz band with a spectrum of 80 MHz (not IEEE 802.11b compliant). The routing protocol is similar to AODV (Ad hoc On-demand Distance Vector Routing, RFC3561), but it is a hybrid protocol because it has both reactive and proactive components. Each node's IP address is fixed to a private IP address calculated from its MAC address automatically, therefore there is no need to manually pre-configure the IP addresses.

Product B

Product B works over a frequency band of 902 – 928 MHz which makes it different than the others in the sense that it is not as dependent on line-of-sight as the 2.4 GHz variants. Again, AODV provides the ad hoc routing functionality for this product. Each node requires prior static IP address configuration.

Product C

Product C combines TBRPF (Topology

Dissemination Based on Reverse-Path Forwarding protocol, RFC 3684), and an IEEE 802.11b compliant radio. Similar to product B, each node requires prior IP address configuration.

In addition to the above, we also experimented with IEEE 802.11b ad hoc mode as a baseline for one-hop comparisons (note that basic IEEE 802.11b does not "hop" more than once).

Experimental Setup, Methodology and Evaluation Results

Experiments described below were performed between June 2003 and February 2004 in New Jersey, and Ohio, USA. Specifically, tests were performed on interstate highways, local roads, open spaces without foliage and a proving track. For brevity, we will not go into details of results of each testing area with different environment characteristics, but we will give average figures as representative performance of each measured item. Also, we will not go into signal strength measurement details.

For each product, we setup several cars with laptop computers connected to cameras, microphones and speakers. For systems with PCMCIA cards, we installed the ad hoc equipment directly on the laptops and for systems with external boxes we connected them via Ethernet ports of the laptops.

Figure 1 depicts a multihop capability test setup with several cars. For each system, maximum distance between the vehicles and the number of maximum hops vary as described below.

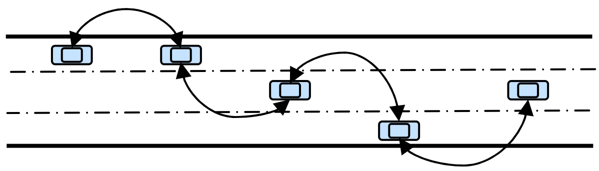

Figure 1. Multihop capability testing.

In order to gain initial insight with each system, we started with baseline experiments which involved two end systems only. This step provided us with data about maximum throughput, end-to-end delay, and maximum reach of the radios while the cars were stationary. In addition to file transfer, we ran a VoIP application to gauge the "human acceptability" of interactive conversation. Once the maximum range of radio signals was reached, we measured and moved to the next step by adding another hop. These steps were repeated for each system until the end-to-end throughput vanished to a useless value and the VoIP application quality became unacceptable.

We also performed tests in order to understand the time it takes for a node to be recognized by a group of other nodes, and the time it takes for a given topology to self-heal when a node is removed.

Table 1 and Figure 2 summarize all of the performance results. Figure 2 is a comparison of throughput performance of all three products with varying number of hops. Note the exponential decay in throughput as the number of hops increases. At the time of the writing of this paper, we have not experimented with more than three hops with product C despite its potential to go further.

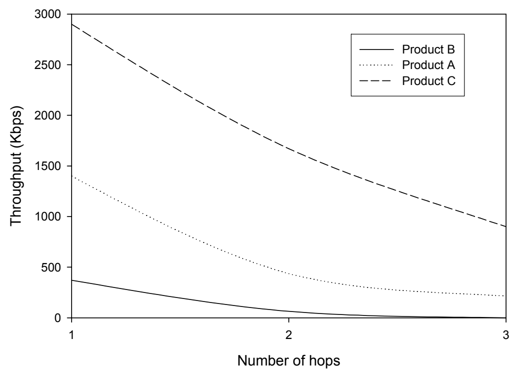

Figure 2. Multihop throughput.

Table 1 has a couple of columns that need some explanation here. First of all, 802.11b is given for reference in this table. The basic 802.11b does not have multihopping capability, however it provides us with a baseline insight on the results obtained from other products. The throughput values given here are the maximum throughput of each product over a single hop.

We see that 802.11b has a remarkable throughput performance compared to its output power (T/P efficiency column). Product B which works over 900 MHz gives the longest reach of all products.

However, normalizing this distance with the power output ($\pi r^2/P$), we see that 802.11b is better optimized. In terms of connection times, product C performs slower than the others, which may be quite acceptable for stationary nodes, but not for mobile ones.

Note that new versions of each of these

	Throughput: T (Kbps)	Power: P (mW)	Throughput Efficiency: T/P (Kbps/mW)	Maximum reach: r (meters)	Efficiency $\pi r^2/P$ (m^2/mW)	Connection time (sec)	Max number of hops
802.11b	3,900	31.6	123.41	500	24,854	> 0.1	1
A	1,400	160	8.75	500	4,908	~ 2	4
B	370	590	0.69	1600	13,631	< 5	3
C	2,900	200	14.5	350	1,924	> 30	>3

Table 1. Summary of experimental performance results.

products have been coming out ever since we started testing with them. We have not yet experimented with all of the newest versions of these products, which, to our knowledge, some have dramatically improved the performance.

III. PROBLEM AREAS

In this section we discuss some of the results and provide qualitative analysis of what we have experimented with these entirely "black boxes". Black box implies that any conclusions we derive from the experiments are inferred from what is available on the public domain and what we have observed from our experiments.

The most important lesson Table 1 provides is that, although a certain product may excel in a certain performance criteria, it usually fails in fulfilling another one.

Connection setup time is the most stringent requirement of a vehicle safety assistance system. The systems we have tested so far do not exhibit the desired setup time which is expected to be in msec order. Most of the current systems implicitly depend on apriori configuration of nodes and possible access to central servers.

In a vehicular environment, apriori configuration of nodes is an unrealistic assumption. In other words, nodes need a dynamic, distributed way to determine whom they should connect to or how to establish their ad hoc groups. Maintaining a route requires certain degree of updating and this can consume bandwidth as mobility increases and topology changes frequently.

On the other hand, we have seen that multihop throughput rapidly dissolves into an almost useless value after a few hops. Ad hoc networks generally tend to break as the number of nodes increase due to the explosive growth in the number of routing messages. Maximum possible hop number varies depending on the system details, however, the degradation is mostly due to channel sharing, route discovery and maintenance, and number of concurrent active connections going through the same node.

Link connectivity and signal strength over a link causes fluctuations in the routes. If a certain path can not be kept long enough, TCP will be adversely affected which will, in turn, decrease the throughput.

IV. A NEW ARCHITECTURE PROPOSAL

In a typical traffic scenario, vehicles do not have any relationship with each other and the neighboring vehicles change continuously. Communicating among unrelated and uncoordinated vehicles in a dynamically changing environment while sustaining a certain throughput as well as keeping connection setup times at minimum is a daunting task. One way of attempting to solve this problem is to use a non-organized flooding-based approach. With flooding, information can be disseminated among vehicles in an uncontrolled manner. However, this will generally result in poor utilization of wireless resources (i.e. channel). It is also challenging to attain scalability with this method.

As an alternative approach, we propose to group the vehicles on a roadway so that a certain degree of coordination among vehicles can be obtained. We believe that, by doing so, it will be possible to design more efficient and reliable protocols within each group.

By grouping vehicles in a neighborhood, we divide the original problem of flat intervehicle communications into more manageable chunks. Note that, by grouping a certain number of vehicles into a chunk, we introduce a virtual boundary around these vehicles (Figure 3).

Groups allow us to control the "range" of messages delivered and the direction of such messages.

The grouping shown in Figure 3 is an example of physically exploiting the instantaneous positions of vehicles. In other words, in this example, geographical positions of vehicles and the tendency to form groups while driving establish two separate groups naturally. However note that, establishing the groups is only the first (though crucial) step towards maintaining a suitable communication pipe among the group members.

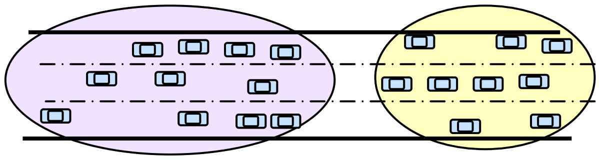

Figure 3. Grouping of vehicles (position-based).

There may be some instances where physical and geographical grouping do not make much sense. Figure 4 illustrates an example of such an instance. In this scenario, vehicle positions lend themselves for a grouping such as in Figure 3, however, there may be such an application that grouping as shown in Figure 4 yields to better information dissemination.

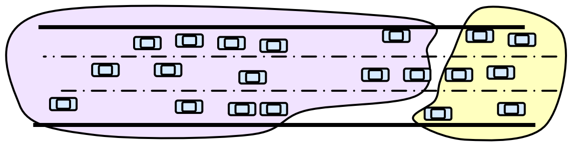

Figure 4. Application-based grouping.

Finally, there may be cases in which a partial overlay grouping among two or more separate groups could be more advantageous than both the position-based and application-based group forming approaches. An example of such an overlay is shown in Figure 5 where a certain number of vehicles belong to the overlay group in the middle.

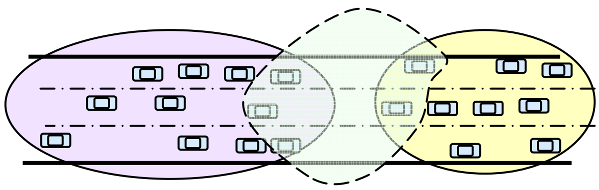

Figure 5. Partial grouping among separate groups

We have so far presented three example methods of grouping among vehicles. One can come up with more examples where situational and physical characteristics combined in certain ways produce more specific ways of generating groups.

Note that, in this paper we will not describe details of how systematic groups are formed and maintained. For a comprehensive treatment of forming and organizing groups, maintaining them, defining group memberships, in-group and inter-group communication methods, and several other key design issues refer to [2].

V. SUMMARY AND CONCLUSIONS

In this paper, we first looked at some of the commercially available ad hoc networking products in order to assess the capabilities and limitations of the present technologies from the viewpoint of vehicle-to-vehicle communications. We described experiments and results addressing throughput, communication range, multihopping capability, and connection setup time characteristics of three off-the-shelf products.

Our preliminary results showed that while each product exhibits some desirable characteristics, none of the tested systems meet all of the stringent requirements of a vehicular application.

We also provided a qualitative analysis of what the problem areas are and how they can be improved leading to the proposal of a new grouping scheme.

The grouping scheme introduced here and described in detail in [2] will make intervehicle communications more effective compared to flat flooding approaches for information dissemination.

REFERENCES

[1] O. Altintas, T. Honda, S. Cai, C.-W. Lee and W. Chen, "Experimental Performance Results of Commercially Available Ad hoc Networks," *Proc. First IEICE Ad hoc Network Workshop*, pp.127-130, Tokyo, Jan. 2005.

[2] W. Chen, J. Chennikara-Varghese, J. Lee, M. Pang, S. Cai, T. Hikita, and O. Altintas, "Ad-hoc Peer-to-Peer Network Architecture for Vehicle Safety Communications," *to appear in IEEE Communications Magazine*, vol.43, no.4, Apr. 2005.

[3] IETF Mobile Ad Hoc Networks (MANET) Working Group, *http://www.ietf.org/html.charters/manet-charter.html*