The Vehicular Delay-Tolerant Networks (VDTN) Euro-NF Joint Research Project

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***Abstract*—The Vehicular Delay-Tolerant Networks (VTDN) project proposed a novel architecture for VDTN. Besides positioning the bundle layer below the network layer, it employs out-of-band signaling and devises the separation of the control plane and data plane. A laboratory prototype was created to demonstrate this approach. The project also developed new applications, fragmentation mechanisms, content storage and retrieval mechanisms, dropping and scheduling policies, and routing protocols for VDTNs.**

***Index Terms*— Vehicular Delay-Tolerant Networks, Delay/Disruption-Tolerant Networks, Vehicular Ad Hoc Networks, Prototype.**

I. Vehicular Delay-Tolerant Networks

DELAY-TOLERANT Networks (DTNs) [1] are networks that enable communication where connectivity issues like sparse and intermittent connectivity, long and variable delay, high latency, high error rates, highly asymmetric data rate, and even no end-to-end connectivity exist. Instead of working end-to-end, in DTNs, a message-oriented overlay layer called "Bundle Layer" employs a store, carry and forward message switching paradigm that moves messages from node to node, along a path that eventually reaches the destination. The idea is to "bundle" together all the information required for a transaction, minimizing the number of round-trip exchanges, which is useful when the round-trip time is very large.

Vehicular Delay-Tolerant Networks (VDTNs) are DTN inspired networks where vehicles communicate with each other in order to disseminate data using data bundles (aggregation of datagrams) as a data unit. Some of the potential applications for these networks include road safety, traffic monitoring, driving assistance, entertainment, advertisements, delivering non real-time Internet connectivity such as eMail or Web access to rural/remote communities or catastrophe-hit areas, and gathering information collected by vehicles such as road pavement defects.

VDTNs are part of a family of opportunistic, self-organized, and autonomous networking area that have arisen from the widen use of wireless communications, where network disruptions are common. In addition, future smart applications [2] will rely on smart mediation techniques that hide the type of underlying network and connectivity problems, providing the best possible service wherever the user is.

A layered architecture for VDTNs was proposed in [3] as illustrated in Fig. 1. The bundle layer is placed below the network layer instead of over the transport layer as in the DTN architecture. The objective is to route large size bundles instead of small size IP packets. This results in fewer packets processing and routing decisions, which can be translated to less complexity, lower cost, and energy savings.

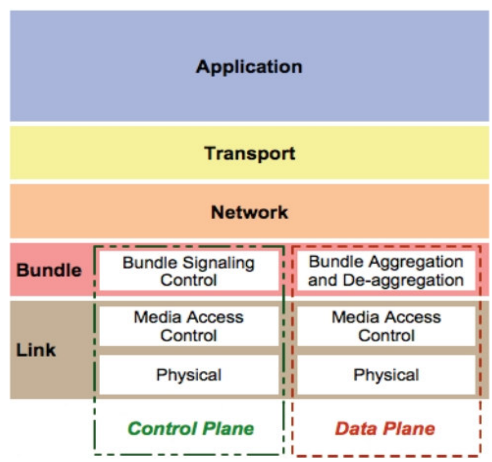

Fig. 1. Vehicular delay-tolerant networks architecture.

The VDTN architecture uses out-of-band signaling, based on the separation of the control plane and data plane. The Bundle Aggregation and De-aggregation (BAD) layer aggregates incoming IP packets into bundle messages that are transferred in the data plane and de-aggregated at the destination. The Bundle Signaling Control (BSC) layer provides a signaling protocol for use at the connection setup phase. The nodes exchange control information to discover each other's characteristics and prepare the data transfer to occur in the data plane. The separation of the control and data planes is conceptually similar to Optical Burst Switching.

A simulation tool, called VDTNsim [4], and a laboratory testbed, called VDTN@Lab, were developed to support research studies related with the development,

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experimentation, and performance evaluation of protocols, algorithms, services, and applications for VDTNs. Fig. 2 shows the VDTN@Lab prototype. The testbed uses Lego Mindstorm NXT robotic cars with notebooks or PDAs for emulating mobile nodes and laptops or desktops for emulating relay nodes and terminal nodes.

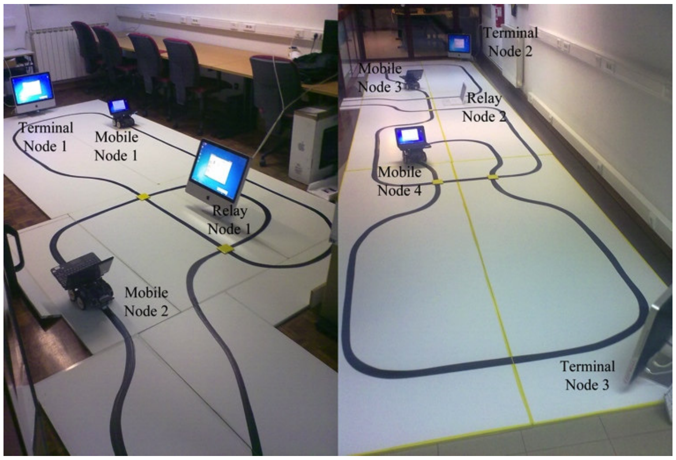

Fig. 2. Photos of the vehicular delay-tolerant network laboratory testbed.

Several DTN-based routing protocols were evaluated on the VDTN@Lab testbed, in conjunction with various scheduling and dropping policies. This study was published in [5].

Based on available content storage and retrieval mechanisms [6], new approaches for VDTNs were proposed [7][8]. Storage and retrieval control labels are attached to data bundles defining cacheable contents, applying cache-control and forwarding restrictions on data bundles. This solution is fully automated, providing a fast, safe, and reliable data transfer and storage management, while improves the use and the performance of VDTN networks.

Web browsing and file transfer applications for VDTNs were developed and its performance assessed [9][10]. The applications work properly, showing that non-real time Web browsing and files transfer can be deployed on VDTN networks.

Two bundle fragmentation and reassembly mechanisms were developed and evaluated in the testbed [11]: reactive and proactive fragmentation. Reactive fragmentation adapts the fragment size dynamically to the duration of the contact, while proactive fragmentation requires an *a priori* definition of the fragment size.

A real-world VDTN testbed [12], based on knowledge and contributions gathered from the VDTN@Lab testbed, was introduced. It demonstrates and validates the technical concepts of the architecture in a real environment.

New routing protocols for VDTNs are being proposed and their evaluation through simulation is being finalized. One is biologically inspired on the ants behavior and another, called GeoSpray, takes routing decisions based on geographical location data.

II. Conclusions and Future Work

Vehicular networking has been the focus of an increasing interest from both academia and industry in the last few years, mainly because of its potential for enabling a plethora of novel applications and services. Nevertheless, many challenges remain to be solved before large-scale vehicular networks can be widely deployed. This paper presents the achievements of the project on VDTNs. It was shown that VDTNs are a promising technology for vehicular communications in scenarios with no network infrastructure or intermittent connectivity. Several protocols, algorithms, and applications were proposed, evaluated, and demonstrated.

VDTNs face various challenging issues that deserve future research work such as node cooperation, mobility pattern, network topology, network management, protocol scalability, traffic type, traffic scheduling, routing protocols, bundle aggregation and fragmentation, security, and more supported applications. Several of these aspects will be studied in a spin-off research project, including tests in car prototypes of a major car manufacturer, if funded.

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