

**09071 Abstracts Collection**  
**Delay and Disruption-Tolerant Networking**  
**(DTN) II**  
— **Dagstuhl Seminar** —

Kevin Fall<sup>1</sup>, Cecilia Mascolo<sup>2</sup>, Jörg Ott<sup>3</sup> and Lars Wolf<sup>4</sup>

<sup>1</sup> Intel Berkeley Labs, USA  
kfall@intel.com

<sup>2</sup> University of Cambridge, GB  
cecilia.mascolo@cl.cam.ac.uk

<sup>3</sup> Helsinki University of Technology, FIN  
jo@netlab.hut.fi

<sup>4</sup> TU Braunschweig, D

**Abstract.** From 08.02. to 11.02.2009, the Dagstuhl Seminar 09071 “Delay and Disruption-Tolerant Networking (DTN) II” was held in Schloss Dagstuhl – Leibniz Center for Informatics. During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general. Links to extended abstracts or full papers are provided, if available.

**Keywords.** DTN, simulations, mobility, MANET, delay-tolerant networking, ad-hoc networking, routing

**09071 Executive Summary – Delay and Disruption-Tolerant Networking (DTN) II**

Today’s Internet architecture and protocols, while perfectly suitable for well-connected users, may easily experience serious performance degradation and entirely stop working in more challenged networking environments. These corresponding scenarios all share two commonalities: that an end-to-end path between two communicating nodes may not exist at any single point in time and that communication delay may be significant. With the continued expansion of the Internet into new areas, these environments become commonplace and are no longer restricted to exotic sensing applications but are quickly becoming relevant to consumers in everyday life. Many attempts over recent years of incrementally fixing the Internet protocols in a bottom up fashion have only achieved partial successes, and a more fundamental approach is needed to address networking environments in which delays and disconnections may last for significant periods

of time, and are the rule rather than the exception. Delay-tolerant Networking (DTN) has taken a more encompassing approach to dealing with virtually all types of connectivity challenges, from bit rate to errors to delays to disruptions. By providing a novel communication abstraction that relies exclusively on asynchronous hop-by-hop message passing with no need for instant end-to-end connectivity, DTN concepts enable communications even under adverse conditions. This comes, however, at the cost of interactivity of communications, rendering any kind state synchronization or validation more difficult and raising new challenges. These include routing protocols – that need to operate under often unknown future conditions, security mechanisms – that can no longer carry out instant key derivation or validation even if a security infrastructure was in place, and application protocols and paradigms – that can no longer rely on simple lower layer abstractions promising (mostly) instant and reliable interactions.

*Keywords:* DTN, simulations, mobility, MANET, delay-tolerant networking, ad-hoc networking, routing

*Joint work of:* Fall, Kevin; Mascolo, Cecilia; Ott, Jörg; Wolf, Lars

*Extended Abstract:* <http://drops.dagstuhl.de/opus/volltexte/2009/2357>

## Contact Graph Routing in the Deep Impact Network Experiment

*Scott Burleigh (Jet Propulsion Laboratory, US)*

The Deep Impact Network (DINET) project was an experimental validation of "ION" (Interplanetary Overlay Network), JPL's implementation of the Delay-Tolerant Networking protocols. In this experiment, the EPOXI (formerly Deep Impact flyby) spacecraft, 14-24 million km from Earth, functioned as a space-based DTN router in an 11-node network of time-varying topology over scheduled episodic links. 292 image files totaling 14,414,849 bytes were transmitted automatically through the network over four weeks without data loss or corruption, while human intervention was limited to loading and booting the software and uploading occasional corrections to the spacecraft clock. The mechanism for achieving automatic, dynamic routing in this delay-tolerant network was Contact Graph Routing (CGR). This talk will provide an overview of CGR with some notes on its specific application to DINET.

*Keywords:* CGR, DINET, contact graph routing

## Opportunistic Mobile Social Networks

*Augustin Chaintreau (Thomson - Boulogne, FR)*

A network is navigable if a simple decentralized scheme allows efficient routing (i.e. in a polylogarithmic number of steps).

Previous works have shown that general classes of graphs can be made navigable by adding few links according to an appropriate distribution. However, for most of these graphs, navigability is sensitive to small deviations from this distribution. Moreover, it seems difficult for the nodes to manage such a link addition in a distributed way. In spite of some efforts, and evidence of the "small-world phenomenon" in social networks, no model currently proves the emergence of navigability from local dynamics.

Here we prove that navigability emerges from nodes' own mobility and memory. Inspired by emerging opportunistic mobile networks using human-carried devices (a.k.a. Pocket switched networks), we model a network where nodes move (in our case, according to a random walk in dimension  $d$ ), and may opportunistically create connections as they meet physically. Once established, these connections are randomly maintained or forgotten, based only on their current age. We prove that this simple setting allows one to create navigable networks. We present a few applications of these techniques to design opportunistic spatial gossip, and discuss the upcoming challenges in relation with recent experiences on using social software for opportunistic mobile networks.

(this is a joint work with Pierre Fraigniaud and Emmanuelle Lebhar, from CNRS-Université Paris Diderot and CMM-Universidad de Chile)

*Keywords:* Social networks, small world navigation, opportunistic networks, peer-to-peer networks, content sharing

*Full Paper:*

<http://www.thlab.net/~chaintre>

## Report of "Pragmatist's" discussion session

*Elwyn Davies (Folly Consulting - Soham (Cambridgeshire), GB)*

Short report of discussions amongst a subgroup of the participants classified as "Pragmatists". The discussion related to a small set of topics (Naming and Addressing, Network Management, Benchmarking). In this sense we were covering issues that could actually pragmatically affect a deployment in the real world currently or in the near future.

*Keywords:* Addressing, naming, routing, benchmarking, network management

## DTN in Public Transportation Networks – Commercial and Environmental Applications

*Michael Doering (TU Braunschweig, DE)*

In this talk we outline an upcoming cooperation with a traffic engineering company.

The goal of this project is to develop a mobile information system based on DTN in order to implement innovative applications for passenger information, infrastructure management and environmental monitoring in the city of Braunschweig, Germany. For this, buses, trams and information terminals at stops will be equipped with low-cost embedded systems to create a city-wide DTN.

*Keywords:* DTN, Public Transportation, passenger information

## **N4C, Testbeds and Living Laboratories**

*Avri Doria (Luleå University of Technology, SE)*

A brief introduction to the N4C project goals regarding Test Beds and Living Laboratories. Also introduces some of the questions that need to be answered in terms of putting testbeds on a 'scientific' basis.

*Keywords:* Testbeds, DTN

## **DTN testbeds**

*Stephen Farrell (Trinity College Dublin, IE)*

We plan to have an extended discussion on DTN testbeds, with folks reporting on existing work and trying to figure out how to better make existing testbeds useful and maybe even work together.

## **1 Byte and Me**

*Philip Ginzboorg (NOKIA Research Center - Helsinki, FI)*

While designing a security feature for mobile ad-hoc network, we have spent between two and three working days in deciding how to save one byte in a message header and were lead to ask: "Is this really needed? Why should one care?"

This talk contains an answer that we came up with and several examples of how *not* to save bytes (and thus energy).

*Keywords:* Energy, protocol design

## **Resource Control for Publish/Subscribe-based Multicast in DTNs**

*Janico Greifenberg (Dampsoft GmbH - Damp, DE)*

We discuss the problem of controlling resource usage for multicast content distribution in DTNs.

Starting from epidemic routing as a bottom-line, we evaluate different trade-offs for the key-metrics reliability (delivery ratio), immediacy (delay), and resource consumption (usage of persistent storage and links). Based on preliminary simulation results, we show what effect different choices for prioritization, filtering, and propagation of subscriptions (i.e. group membership information) have on the key-metrics.

With the talk we hope to initiate a discussion on how multicast can be used effectively in resource-constrained environments.

*Keywords:* Publish/Subscribe, Multicast, Resource Control

*Joint work of:* Greifenberg, Janico; Kutscher, Dirk

## On the Performance of Pedestrian Content Distribution

*Gunnar Karlsson (KTH - Stockholm, SE)*

Mobile communication devices may be used for spreading multimedia data without support of an infrastructure. Such a scheme, where the data is carried by people walking around and relayed from device to device by means of short range radio, could potentially form a public content distribution system that spans vast urban areas. There are basically only three system parameters that can be determined in the design: the transmission range of the nodes, the setup time when nodes make a contact, and their storage capacity. The transport mechanism is the flow of people and it can be studied but not engineered. The question addressed in this paper is how well pedestrian content distribution may work. We answer this question by modeling the mobility of people moving around in a city, constrained by a given topology. The model is supplemented by simulation of similar or related scenarios for validation and extension. Our conclusion is that contents spread well with pedestrian speeds already at low arrival rates into a studied region. Our contributions are both the results on the feasibility of pedestrian content distribution and the queuing analytic model that captures the flow of people.

*Keywords:* Content distribution, mobile peer-to-peer, ad hoc network, wireless network, mobile communication

*Joint work of:* Helgason, Ólafur Ragnar; Karlsson, Gunnar; Vukadinovic, Vladimir

*Full Paper:* <http://drops.dagstuhl.de/opus/volltexte/2009/2359>

## **IBR-DTN: An efficient Implementation for Embedded Systems**

*Johannes Morgenroth (TU Braunschweig, DE)*

We present an implementation of DTN for embedded systems and demonstrate how a WLAN access point can be turned into a stand-alone DTN-node for mobile applications. The modular software design of IBR-DTN is centered on the efficient use of resources and interoperability with the DTN2 reference implementation. Our modules comprise a DTN Core, Bundle Router, Persistent Storage and a Convergence Layer Manager. IBR-DTN is work in progress, but the comparison of the features and performance to DTN2 is already very promising. Our demonstration platform was presented at Chants 2008.

*Keywords:* Implementation, embedded system, software, wlan

## **Connectivity Models for the Evaluation of DTN Systems**

*Mirco Musolesi (University of Cambridge, GB)*

The testing of the performance of delay tolerant communication protocols and systems is usually done through simulation as i) deployments are expensive and should be left to the final stage of the development process, and ii) the number of varying parameters in these systems is so high that it would be very hard to conduct thorough testing of all the functionality within a single deployment. Therefore, protocols are often plugged into mobility simulators to test their performance; however, until recently, most of the testing has been conducted with random mobility models which do not mirror reality. Furthermore, despite disconnections playing a very prominent role in the performance of any delay tolerant mobile system, most models do not really account for it. A different approach to the performance evaluation of this class of systems is the use of real traces of movement collected in specific domains. However, these traces do not allow for flexible performance testing, as they are specific for a given scenario with fixed connectivity properties.

In this talk I will discuss our work on connectivity models for the evaluation of delay tolerant networked systems. I will present the Connectivity Trace Generator (CTG), a tool for the automatic generation of connectivity traces, which takes as input real mobility traces and is able to output a set of traces with similar connectivity properties. This allows system designers to investigate the impact of the variation of connectivity patterns, number of hosts, and other parameters on the protocol or system under investigation. Finally, I will outline and try to foster a discussion about the open research issues in designing effective connectivity models for delay tolerant networking.

*Keywords:* Connectivity models, performance evaluation, testing

## Searching for Content in Mobile DTNs

*Mikko Pitkänen (Helsinki University of Technology, FI)*

Delay-tolerant Networking (DTN) provides a platform for applications in environments where end-to-end paths may be highly unreliable or do not exist at all. In many applications such as distributed wikis or photo sharing, users need to be able to find content even when they do not know an unambiguous identifier. In order to bring these applications to the domain of DTNs, a search scheme is required that works despite the unreliable network conditions. In this paper, we introduce a search scheme that makes no assumptions about the underlying routing protocols and the format of search requests. We evaluate different algorithms for forwarding and terminating search queries, using simulations with different classes of DTN routing protocols for different mobility scenarios.

*Keywords:* DTN, Mobile, Web Content, Search

## Leveraging Social Contacts for Message Confidentiality in DTNs

*John Solis (Univ. California - Irvine, US)*

Delay- and disruption-tolerant networks (DTNs) can bring much-needed connectivity to rural areas and other settings with limited or non-existing infrastructures. High node mobility and infrequent connectivity inherent to DTNs make it challenging to implement simple and traditional security services, e.g., message integrity and confidentiality.

In this presentation, we focus on the problem of initial secure context establishment in DTNs. Concretely, we design a scheme that allows users to leverage social contact information to exchange confidential and authentic messages.

*Joint work of:* El DeFrawy, Karim; Solis, John; Tsudik, Gene

## Wireless Epidemic Spread in Dynamic Human Networks

*Eiko Yoneki (University of Cambridge, GB)*

The emergence of Delay Tolerant Networks (DTNs) has culminated in a new generation of wireless networking. New communication paradigms, which use dynamic interconnectedness as people encounter each other opportunistically, lead towards a world where digital traffic flows more easily. We focus on human-to-human communication in environments that exhibit the characteristics of social networks. This paper describes our study of information flow during epidemic spread in such dynamic human networks, a topic which shares many issues with network-based epidemiology. We explore hub nodes extracted from real world connectivity traces and show their influence on the epidemic to demonstrate the characteristics of information propagation.

8 Kevin Fall, Cecilia Mascolo, Jörg Ott and Lars Wolf

*Keywords:* Time Dependent Networks, Connectivity Modelling and Analysis, Network Measurement, Delay Tolerant Networks, Social Networks

*Joint work of:* crowcroft, Jon; Hui, Pan; Yoneki, Eiko

*Full Paper:* <http://drops.dagstuhl.de/opus/volltexte/2009/2358>