INRIA International program
Associated Team Final Report 2011

Name of the Associated Team: COMMUNITY

URL of the Associated Team: `http://inrg.cse.ucsc.edu/community/`

A. Scientific report

A1.Did the goals shifted along the completion of the project?

Our initial scientific objective throughout the project was to design efficient message delivery mechanisms for challenged and heterogeneous networks. The original proposal targeted the following contributions:

- The development of a unifying solution to enable message delivery over heterogeneous networks with varying degrees of connectivity.
- The development of error- and congestion control techniques in episodically connected networks.
- The exploration of different mechanisms for quality-of-service (QoS) support in such environments.

We have re-oriented some of the initial proposed research. In particular, rather than investigating error and congestion control techniques for DTNs, we focused on the development of efficient routing strategies that take into account the *utility* of nodes to relay messages. Furthermore, we decided to work in the area of naming because it was essential for the project that we developed a naming scheme that supports message delivery over heterogeneous networks prone to connectivity disruptions.

More recently, we have been investigating new information-centric network architectures. More specifically, we have been exploring software-defined networking (SDN) as a way to develop and deploy innovative network protocols for the future Internet.

A2. State the scientific results of the Associated Team

Advancement beyond the state-of-the-art

The main scientific contributions of the COMMUNITY Associated Team are as follows:

- **Design of MeDeHa (Message Delivery in Heterogeneous, Disruption-prone Networks):** We developed a framework that aims to enable efficient message delivery (point-to-point as well as multi-point) across heterogeneous networked environments, including networks prone to episodic connectivity. The proposed framework copes with arbitrarily long-lived connectivity disruptions by using available storage within the network to store messages for destinations that are currently unreachable; once these destinations re-connect, messages destined to them get delivered. MeDeHa also supports different levels of quality-of-service through traffic differentiation and message prioritization. References [1],[5],[6],[8],[9], and [10] describe our work in detail.

- **Development of routing strategies in challenged network environments consisting of heterogeneous nodes:** We addressed the problem of routing in intermittently connected wireless networks comprising multiple types of nodes. We show that proposed solutions, which perform well in homogeneous scenarios, are not as competent in heterogeneous settings. We thus proposed a class of routing schemes that can identify nodes with highest *routing utility* and showed, through simulations using a variety of heterogeneous environments, that our proposed strategies can improve the delay and delivery ratio by four to five times (See [3] for more details).

- **Development of a taxonomy and design guidelines for challenged networked environments:** Our goal was to identify a set of useful design guidelines that will facilitate the selection of adequate routing protocols for a target application and/or network. To this end, we identified generic network characteristics that are relevant to the routing process (e.g., network density, node heterogeneity, mobility patterns) and analyzed different challenged networks based on these characteristics (See [2], and [7] for more details).

- **Development of a new naming mechanism to support message delivery over heterogeneous networks prone to connectivity disruptions:** We have elaborated a naming mechanism, called HeNNA (Heterogenous Networks Naming Architecture), which supports message delivery across heterogeneous networks including intermittently connected networks. HeNNA decouples an object's identification from its location, and applications use the object's identifier

to access it without having to know their current location (i.e., IP address). HeNNA is designed to be used with current Internet routing, while accommodating node mobility (e.g., change of the node's point of attachment) as well as arbitrarily long-lived disconnections. We have evaluated HeNNA within the ns-3 implementation of MeDeHa (See [4]).

Software, technology development, and transfer

- The MeDeHa framework has been implemented both in simulators (OMNET++ and ns-3) and in a real Linux stack. The code is publicly available from `http://planete.inria.fr/software/MeDeHa/`.
- The Henna naming mechanism has been implemented in the ns-3 simulator and the code is publicly available from `http://planete.inria.fr/software/Henna/`.
- The HBSD joint scheduling and drop policy framework has been integrated into MeDeHa and tested on the SCORPION experimental testbed at UCSC (See `http://planete.inria.fr/HBSD_DTN2/` for more details).

Knowledge sharing among the partners, training of young researchers

Three PhD students and four Master students have been involved in the COMMUNITY Associated Team: (1) Naveed Bin Rais (UNSA 2008-2011) focused on the design and the evaluation of the MeDeha framework and the Henna naming mechanism. He visited UCSC for 2 months in 2009; (2) Amir Krifa (UNSA 2008-2011) worked on the design of the HBSD mechanism, its integration with the SCORPION UCSC testbed, and its interface with MeDeHa. He visited UCSC one month in 2010; (3) Marc Mendonca (UCSC 2011-) worked during his MSc internship on the development of MeDeHa on Linux nodes and its evaluation. He is now a PhD student and is currently visiting INRIA for 4 months; (4) Matt Bromage (UCSC MsC 2009) worked on the design of routing mechanisms for challenges networks; (5) Mariem Abdelmoula (UNSA Ubinet MSc 2010) and Ana Nika (U. of Athens MsC 2011) worked on the implementation and evaluation of the Henna naming mechanism.

B. Outcomes of the Associated Team

B1. Joint papers published under COMMUNITY

International Journals:

1. **R.N.B. Rais, T. Turletti, K. Obraczka**, "Message Delivery in Heterogeneous Networks prone to Episodic Connectivity", to appear in ACM/Springer Wireless Networks (WINET) journal.

2. **T. Spyropoulos, R.N.B. Rais, T. Turletti, K. Obraczka, A. Vasilakos**, "Routing for disruption tolerant networks: taxonomy and design", ACM/Springer Wireless Networks (WINET) journal, Vol. 16, Issue 8, 2010, pp. 2349-2370.

3. **T. Spyropoulos, T. Turletti, K. Obraczka**, "Routing in Delay Tolerant Networks Comprising Heterogeneous Node Populations", **in IEEE Transaction on Mobile Computing (TMC)**, Vol. 8, No. 8, August 2009, pp. 1132-1147.

International Conferences:

4. **R.N. Bin Rais, M. Abdelmoula, T. Turletti, K. Obraczka**, "Naming for Heterogeneous Networks Prone to Episodic Connectivity", *in Proceedings of the IEEE WCNC Conference*, Cancun, Mexico, March 2011.

5. **R.N. Bin Rais, M. Mendonca, T. Turletti, K. Obraczka**, "Towards Truly Heterogeneous Internets: Bridging Infrastructure-based and Infrastructure-less Networks", *in Proceedings of the 3rd IEEE/ACM International Conference on Communication Systems and Networks (COMSNETS)*, India, January 2011.

6. **R.N. Bin Rais, T. Turletti, K. Obraczka**, "Coping with Episodic Connectivity in Heterogeneous Networks", *11th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM)*, Vancouver, Canada, October 2008.

Book Chapter:

7. **T. Spyropoulos, N.B. Rais, T. Turletti, K. Obraczka, A. Vasilakos**, "DTN Routing: Taxonomy and Design", *in Book "Delay Tolerant Networks: Protocols and Applications", published by Auerbach Publications, CRC Press, Taylor and Francis Group*, ISBN: 978-1-4398110-8-5.

Demos:

8. **A. Krifa, M. Mendonca, R.N.B. Rais, C. Barakat, T.Turletti, K. Obraczka**, "Efficient Content Dissemination in Heterogeneous Networks Prone to Episodic Connectivity", *Demo description in Proc. of ACM Sigcomm*, August 2011, Toronto, Canada.

9. **M. Mendonca, R.N.B. Rais, T.Turletti, K. Obraczka**, "Message Delivery in Heterogeneous Disruption-prone Networks", *Demo description in Proc. of ACM Mobicom*, September 2010.

10. **M. Mendonca, R.N.B. Rais, T.Turletti, K. Obraczka**, "Message Delivery in Heterogeneous Disruption-prone Networks", *Invited demo presentation at The ACM second Wireless of the Students, by the Students, for the Students (S3)*, September 2010.

B2. Thesis jointly supervised under COMMUNITY

- Marc Mendonca MSc thesis, UCSC, 2011, on new network architectures.
- Ana Nika MSc Thesis, U. of Athens, 2011, on the enhancement and the evaluation of the Henna naming mechanism.
- Naveed Bin Rais PhD Thesis, UNSA, 2011 on Efficient Transmission Mechanisms for Networks with Episodic Connectivity.
- Mariem Abdelmoula MSc Thesis, Ubinet, Sep. 2010 on Naming issues in challenged networks.
- Matt Bromage MSc Thesis UCSC, Sep. 2009, on Delay-tolerant routing for extreme networking environments.

C. Assessment of the collaboration

C1. What is your assessment of the collaboration, and its added value for the research conducted within your Inria project-team?

The outcome of the COMMUNITY Associated Team so far has been extremely positive. The expertise of Katia Obraczka's team on sensor networks and delay tolerant network architectures is complementary to the Planète project-team's expertise on network protocol design, simulation, and experimentation. This synergy enabled us to design efficient transmission mechanisms for challenged networks and to evaluate them not only with

simulation but in real testbeds at INRIA and UCSC. The exchange of students and numerous on-site meetings were clearly crucial to the success of the collaboration.

C2. Do you foresee further developments to this collaboration?

As mentioned in Section A1, we have been investigating new information-centric network architectures using software-defined networking (SDN). SDN techniques will facilitate the design and the deployment of innovative network protocols for the future Internet. This will be the main focus of the COMMUNITY Associated Team and is described in more detail in the renewal proposal to be submitted separately.

C3. Additional information and remarks

We have just been awarded a grant from the US National Science Foundation (NSF) to explore new information-centric network architectures for the internets of the future using software-defined networking (SDN) techniques. The name of the project is Hybrid Software Defined Networking (H-SDN) and the total funding is $48K for the duration of 1 year. The funding will cover support for graduate students as well as travel for visits to INRIA. This NSF support corresponds to the UCSC financial contribution for the COMMUNITY renewal proposal submitted separately.