A framework for network coding in challenged wireless network

Alaeddine El Fawal, Kave Salamatian, David Cavin, Yoav Sasson and Jean-Yves Le Boudec
School of Computer and Communication Sciences
Ecole Polytechnique Fédérale de Lausanne (EPFL)
{alaeddine.elfawal, kave.salamatian, david.cavin, yoav.sasson, jean-yves.leboudec}@epfl.ch

I. Introduction

Today Internet architecture and protocols operate poorly in environment characterized by uncertain networking conditions, high mobility and frequent network partition. A lot of interest have been attracted during the past couple of years to practical situations where disconnection and reconnection is frequent as in PANs (Personal Area Networks) or vehicular networks, resulting in a new appelation for these scenarios as Delay Tolerant networks (DTN). These problems are aggravated by heterogenity in used appliances (PDAs, laptop, *etc.*), difference in user behaviours (highly mobile vs. static users), power consumption constraints that results in putting communication appliance in "off-line" state as well as various level of collaboration (collaborative vs. selfish users). As a scenario of interest, we might think of a wireless network that is divided into disconnected island of connected users. Nodes circulating between groups transport information that are to be transferred. Under these challenging situations classical routing based approaches are not anymore effective and new forwarding paradigms should be developped.

Network coding is an area that has emerged in 2000 [1], and has since then attracted an increasing interest, as it promises to have a significant impact in both the theory and practice of networks. We can broadly define network coding as allowing intermediate nodes in a network to not only forward but also process the incoming information flows. Linear Network coding processing/forwarding approach consists in choosing a subset of received packets and forwarding a linear combination of chosen packets with random coefficients. Because of the intrinsic broadcast property of wireless networks this linear combination might be received at several receivers resulting in new linear combinations when they are mixed with other packets. At destination, multiple linear combination are received through different paths resulting in a system of linear equations; if the number of independent equations exceed the number of combined packet the system of linear equation could be inverted leading to the initial packets. This is to compare with classical routing approach where only packets that validate a routing criteria are forwarded or flooding where each single packet is forwarded indifferently. Network coding is attractive for challenged networks because of its inherent unsynchronized operation: each node decides to forward a random linear combination without needing any global information about the topology or destination placement. Moreover forwarding a random combination reduces highly the probability of sending redundant packets that is the Achille heel of the flooding approach. Finally Network Coding has been proven to reach Min-cut Max-Flow optimality at least in lossless network with directed graphs in adding to the theoretical attractiveness of the approach.

Up to now, all the above properties have been exhibited in theory. To the best of our knowledge only two implementation of network coding have been reported : one is the avalanche system by microsoft [2] for content diffusion over P2P networks and the second one is the COPS system developped at MIT in the context of wireless mesh networks [3]. These implementations have been designed for different communication scenarios than the one we are interested in. Evaluation in realistic situation of highly dynamic networks of network coding based forwarding paradigms was missing. It was therefore very hard to evaluate the complexity of the decoding step to see if network coding is a viable solution for such challenged neworks. Our development effort have been targeted toward filling this gap.

Before dealing with forwarding paradigms, one has to define a software and system framework for implementing applications in challenged networking conditions. For living in such hostile environment a software framework has to comply with several constraints as portability, flexibility, genericity, *etc.* Moreover to reduce the development effort using a framework where a single implementation might be used as standalone as well as inside a simulation environment is highly desirable. The FRANC (FRamework for Ad hoc Network Communication) Framework [4] has been developped to take up this challenge.

As the developped software is released under a fully open source GNU licence[1] [5], and because of the inherent properties of the FRANC framework we hope it to be used by the whole community for testing, simulating and evaluating new communication paradigms for challenged Mobile Wireless networks.

II. FRANC Framework

FRANC [4] is a lightweight framework tailored to implement and deploy real ad-hoc network applications. Ultimately, the real-life deployment of MANET applications is not only complementary to simulation but indispensable to fully evaluate their performance under realistic settings. FRANC is implemented in Java and thus requires the presence of a Java virtual machine (JVM) to run. The most noticeable benefit is the direct portability of the framework. Whenever a JVM exists for a particular device and operating system, then FRANC can be executed independently from the underlying platform. The other important strengths of FRANC are the flexibility and the modularity of the protocol stack composition and the ability to transparently execute the same code on top of a simulated network.

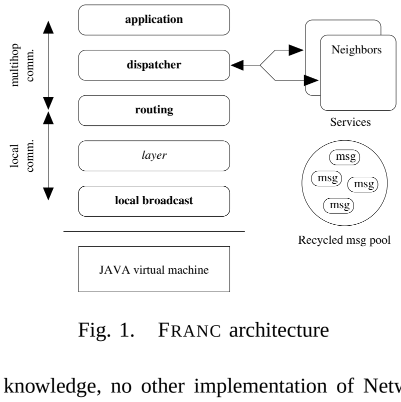

Fig. 1. FRANC architecture

[1]Up to our knowledge, no other implementation of Network Coding is available for free access.

Figure 1 depicts the general architecture of FRANC . It consists of three main components, (1) the protocol stack, (2) the services and (3) the recycled message pool. The protocol stack is composed of a set of ordered layers which defines the application executed on a node. Layers are chosen off-the-shelf and their composition is specified by the user in the configuration file at start-up. Additionally, to weaken the rigid structure of the stack, FRANC implements a mechanism, we call service, that allows to share portions of code by executing them aside the protocol stack. This is, for example, useful to avoid unnecessary duplication of identical features like neighbor detection. With respect to message handling, FRANC compensates the high computing cost of standard Java object serialization (especially on portable devices) with a more flexible user-defined message serialization. Additionally, unused references to messages either sent on the network or whose treatment in the stack has completed, are recycled in a message pool and made available for new message creation.

A. Integration with Jist/Swans simulator

Simulation capabilities remain desirable as a preliminary and cost-effective step to evaluate an application before its deployment. This is particularly true for large networks or complex mobility patterns. To this means, we have integrated FRANC with Jist/Swans [6], a Java-based simulation runtime for mobile ad-hoc networks developed at Cornell University. The benefit of this integration is the capability of either deploying or simulating the same code seamlessly, without any modification. To this means, the FRANC stack is executed independently of Jist and only the networking operations are delegated to the simulator.

III. Network coding implementation features

Our aim was to define a framework where the researcher interested only in forwarding paradigm could focus on a specific part without dealing with applicative and physical layer concerns. The FRANC framework is an excellent answer to this demand. We have implemented Network coding as a layer in the FRANC architecture (Fig. 1) seating between the dispatcher and the physical layer. Because of the modular structure of FRANC one could replace Network Coding with more traditional approaches as Flooding, AODV routing or any new forwarding scheme by just changing some line in the FRANC application stack description file defined in XML.

In the forthcoming we will describe the features of our implementation of network coding.

1) Random Linear Network Coding: As explained previously forwarded packet in network coding are random linear combination of packets inside local buffers. Since coefficients and packets used to construct a forwarded packets are unknown *a priori*, we need to embed these information in each encoded packet. We have therefore constructed a specific message type containing an encoded payload as well as a list containing coefficient and unique packet identifiers of packet combined to make this packet. When a new packet containing a linear combination is received the list of coefficient is extracted and a gaussian pivot elimination step is applied to reduce the order of the equation. If the reduction results in the decoding of one or several packets, the destination is checked to see if the node is the final destination (or if the packet is a broadcast). If it is the case the packets are forwarded to applicative layers.
2) GF(2^8): All operations are done within GF(2^8) Galois Field. This ensures good performance as multiplication can be done trough discrete logarithm tables. This lead to an improvement of a factor up to 100 in encoding and decoding.
3) Contributing packet list limitation: during the course of a transmission the list containing the coefficient and the set of packet used to build an encoded packet inflates and the overhead can become tremendous if nothing is done to limit this number. We have therefore decided to limit the maximal number of packets used to encode one new encoded packet. This number is given as a parameter during the execution.
4) Flooding implementation: Flooding could be considered as a subcase of network coding where the maximal number of contributing packets is fixed to one. We have implemented flooding through this approach to enable the coexistence of network coded and non network coded packets in the same network.

IV. Demonstrated application

In the context of Mobisys 06 conference we propose to make a demonstration of our developped framework to implement a distributed Bulletin Board System (D-BBS) application. participant to the conference will be able to download the application through an applet interface on their WIFI based PDA, laptop computer (or maybe motes) running a JVM. By running the application a chat window will be opened and the user could access to the D-BBS. No configuration parameter will be needed beyond an eventual user ID. The application will be able to tackle with highly dynamic environments and opportunistically send and receive information that will be used to decode the messages sent by other participants. The user will in particular be able to feel the effect of a selfish behaviour consisting of only storing packets that have a part destinated to himself and to compare it with the cooperative behaviour where he agrees to store packet that are not destinated to him and use them for decoding information that are destinated to him.

We will show the interest of the approach in the a disconnected scenario. Let's assume that there exists several group of people that are close to each other and are discussing together. The groups are not in communication range of each other. We will show that whenever a user moves from one group to another he will act as message transporter and create connectivity between groups.

This scenario will be shown in real as well as through simulation inside the JIST/SWANS simulation environment. Up to our knowledge this demonstration will be the first realistic demonstration of network coding in the context of Delay Tolerant networks.

V. Requirements

The demonstration is based on on the fact that no infrastructure is needed. We will just use one laptop generating an WIFI Adhoc network beacon

References

[1] R. Ahlswede, N. Cai, S. R. Li, and R. W. Yeung, "Network information flow," *IEEE Transactions on Information Theory*, July 2000.
[2] C. Gkantsidis and P. R. Rodriguez, "Network coding for large scale content distribution," in *In Proc. IEEE Infocom 2005*, 2005.
[3] S. Katti, D. Katabi, W. Hu, H. Rahul, and M. Medard, "Practical network coding for wireless environments," in *In Proc. of Allerton Conference on Communication, Control, and Computing*, 2005.
[4] D. Cavin, Y. Sasson, and A. Schiper, "Franc: A lightweight java framework for wireless multihop communication," EPFL-IC-LSR, Tech. Rep. LSR-REPORT-2003-016 200322, 2003.
[5] [Online]. Available: http://icawww1.epfl.ch/netcod
[6] R. Barr, Z. J. Haas, and R. van Renesse, "Jist: Embedding simulation time into a virtual machine," in *In Proc. of EuroSim Congress on Modelling and Simulation*, 2004. [Online]. Available: http://jist.ece.cornell.edu