Advance GNU Radio to the Network Level: Progress, Opportunities and Challenges

Feng (Andrew) Ge, PhD

fge@telcordia.com
Telcordia Technologies, Inc.

GNU Radio Conference
September 14–16, 2011
Motivation

*Wireless network R&D needs versatile radio platforms*

Is PHY layer dead [1]? → Go beyond Shannon in MANET [2]

*Wireless networks desire for adaptive capabilities*

- L1/L2: fading, multipath, jamming, interference, contention
- L3/L4: mobility, routing, flow, congestion
- L5: reliability, delay, data volume

(a) Wi-Fi signal fading pattern [3]

(b) Military network
**SDR: a Disruptive Technology for Wireless Networks**

- SDR moves most PHY/MAC functions into the software domain, achieving unparalleled flexibility.
- The whole protocol stack is now in the same computing domain, enabling cross-layer adaptation.

(c) An idealized direct-sampling SDR

(d) A generic software-defined transceiver

- GNU Radio: open source for developing **GPP-based** SDR
GNU Radio in Network Research

Current status

- Cross-layer adaptation [3], MAC protocol design [4]
- Cognitive radio network [5, 6]
- Network coding [7, 8]

However, its use is limited

- Only assistant to Wi-Fi in relevant research [4, 7, 3]
- Existing testbeds provide little network capability
- Latency and its jitter [9]—Achilles’ heel

True MANETs using GNU Radio are yet to be developed
Our Contribution

First to

- Develop a MANET with 10+ GNU Radio nodes
- Build a ten-node cognitive radio network using GNU Radio
- Conduct throughput analysis of GNU Radio-based CSMA
Roadmap

Introduction

GNU Radio in our Network Research
  Outdoor MANET Testbed
  Decentralized Cognitive Radio Network

Future Research and Discussion

Conclusion
GNU Radio Testbed for Tactical Information Technologies for Assured Networks (TITAN)
TITAN

- Current network planning systems lack *mission intent*
- TITAN captures mission intents via policies
- TITAN plans, monitors, diagnoses, re-plans, and re-configures the whole protocol stack
Radio Platform

Prototype system

(e) System Diagram

(f) Prototype
**PHY/MAC**

**Reconfigurable channelization**

![Diagram of channelization](image)

**Multi-channel non-persistent CSMA**

![Diagram of multi-channel non-persistent CSMA](image)
Network Capabilities

10-node MANET

Demonstrated capabilities (not exhaustively):

- Automatic resource redistribution to address network capacity requirement changes
- Application layer data rate adaptation based on network conditions and traffic priority
- Malicious users identification and quarantining
- Neighbor discovery and connection maintenance
Link Capacity

Performance of UDP over Two Flows

Flow One
- Throughput (kb/s)
- Jitter (ms)
- Packet Loss (%)

Flow Two
- Throughput (kb/s)
- Jitter (ms)
- Packet Loss (%)

Average

MAC Performance

Throughput of Carrier Sense Multiple-Access

(g) Experimental setting: 3 transmitters, 1 receiver, 500B/packet, 120kb/s, non-persistent CSMA

(h) Throughput of GNU Radio-based CSMA. S and G are normalized to the channel bandwidth
Decentralized Cognitive Radio Network
Experimental Setting
Distributed Spectrum Management

CWT Dynamic Spectrum Access Broker

Master sensor database:

<table>
<thead>
<tr>
<th>Channel ID</th>
<th>Frequency</th>
<th>Power</th>
<th>Modulation</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dynamic Spectrum Utilization Statistics:

Primary Usage Statistics:

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>4600000000 - 5000000000</td>
<td>47</td>
</tr>
</tbody>
</table>

Secondary Usage Statistics:

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Spectrum Utilization (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>02</td>
<td>47</td>
</tr>
</tbody>
</table>

DSA Broker Table:

<table>
<thead>
<tr>
<th>ID</th>
<th>Frequency (Hz)</th>
<th>Power (dBm)</th>
<th>Bandwidth (Hz)</th>
<th>Occupancy</th>
<th>User Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4625610154</td>
<td>-68.44</td>
<td>26093256</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>1</td>
<td>4625610154</td>
<td>-68.44</td>
<td>26093256</td>
<td>0</td>
<td>Primary</td>
</tr>
</tbody>
</table>

DSA Broker Cognitive Radio (CR) Registry:

<table>
<thead>
<tr>
<th>Index #</th>
<th>IP Address</th>
<th>Frequency</th>
<th>Bandwidth (Hz)</th>
<th>Modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>322.168.0.5</td>
<td>9700</td>
<td>26037972</td>
<td>GMSK</td>
</tr>
<tr>
<td>1</td>
<td>322.168.0.6</td>
<td>9700</td>
<td>26037972</td>
<td>GMSK</td>
</tr>
<tr>
<td>2</td>
<td>322.168.0.10</td>
<td>9700</td>
<td>26037972</td>
<td>GMSK</td>
</tr>
</tbody>
</table>
Node Architecture and MAC

(i) Node architecture

(j) MAC for DSA

Channelized PHY layer is used; system details available in [6].
Throughput variation during an DSA session; detailed performance analysis available in [6].
Future Research and Discussion
GNU Radio is Crucial to Wireless Network Research

GNU Radio may overtake Wi-Fi in MANET research

- Wireless network research trends: cross-layer, cognitive radio/network, MIMO, network coding, power efficiency, relay/cooperation, etc.
- Needs: versatile radio platforms, vastly available PHY/Link layer libraries, easy environment for new code development
- GNU Radio (and USRP) provides most needs

However, it has yet to conquer the network level
Challenges for SDR-Based Wireless Network

Computing, communications, and networking converge into one domain, thereby demanding holistic research

- Demand for knowledge in RF, signal processing, communications theory, computer architecture, operating system, algorithm, and networking theories
- Complex inter-play among wireless communications, computing resource allocation, and networking performance support

Innovative architecture, protocols, and models are needed

- SDR-based MANET is fundamentally different
- Profound research is required, e.g., are there any Shannon-limit like bounds?

Unprecedented system complexity
Example Challenge 1: Computational Demand

The demand for CPU is too much [10]

(k) CPU demand vs. receiving data rate
(l) CPU demand vs. transmission data rate

Optimization is desperately needed!

- Three levels: instruction, algorithm, and system
- Parallelism [11]: TPB (task level), VOLK (SIMD), next}\textsuperscript{Telcordia}}
Example Challenge 2: Execution Latency

**SDR execution latency**

Processing, scheduling, queueing, I/O, and memory hierarchy

*The impact of latency on MAC performance is dramatic*

(m) Execution latency \((a)\) is the ratio of a packet’s propagation and processing delay over its communication time)

(n) Throughput of CSMA [12]
Conclusion

- Introduced our progress on advancing GNU Radio to the network level
- Discussed some major challenges for GNU Radio moving to the network level
- Explored GNU Radio’s future opportunities in wireless network research
Acknowledgement

TITAN has been supported by the U.S. Army Communications Electronics Research and Development Engineering Center (CERDEC) with contract number W15P7T-08-C-P213. The views and conclusions contained in this document are those of the authors and should not be interpreted as presenting the official policies or position, either expressed or implied, of the U.S. Army CERDEC, or the U.S. Government unless so designated by other authorized documents.

Cognitive radio network testbed was based upon work supported by the National Science Foundation under Grant CNS-0519959. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation (NSF).
Reference


