GENI Experimental Infrastructure – Wireless & Sensor Networks

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GENI Wireless Network Implementation Plan
GENI Implementation: Wireless Platforms

- Flexible wireless networking platforms to be designed for GENI
  - End-user/client devices including laptops, mobile handsets and sensors
  - Internal network devices including radio access point, wireless router and sensor gateway

- Design objectives for wireless platforms
  - Designs should support multiple radios technologies (as “plug in”), provide open API’s to layers 1-3 (radio, MAC and network), and have a common open-source software framework
  - Network nodes should be support software download and multiple protocols and interoperate with virtualized network nodes used in core infrastructure
  - Network nodes should support remote monitoring and rebooting features – important for network operation and management

Example Implementations:

1. Sensor platform
   - Embedded CPU board
   - Radio Module
   - Example implementations: MICA/Mote
   - Integrated cell-phone platforms + open API

2. Mobile Platforms
   - Commercially available devices + Open API radio cards
   - WLAN
   - UMTS
   - Integrated cell-phone platforms + open API

3. AP/BTS/Forwarding Node/Sensor GW
   - CPU board
   - Radio Module
   - Wired I/F
   - Example implementation: ORBIT dual-radio node

4. Radio Router
   - CPU board
   - Radio Card
   - Switch fabric
   - Wired I/F
   - 802.11
   - Cognitive radio
   - 3G/WiMax radio

Example implementation: ORBIT dual-radio node
GENI Implementation: Wireless Platforms (contd.)

- GENI platforms developed using following core modules
  - Embedded CPU for sensors
  - CPU platform for general purpose radio node
  - Commercial mobile computing and cell phone platforms
  - Switching platform for radio router
  - Radio modules: Mote, Zigbee, 802.11x, WiMax, 3G, cognitive - custom development work may be required to ensure open API for flexible use

- Software for GENI wireless platforms
  - Linux open-source on all modules except certain low-power sensors (e.g. Mote)
  - Uniform radio API for control of power, frequency, bit-rate etc. & PHY measurements
  - Uniform soft MAC API for control of packet transmit format/time
  - Experiment downloading software compatible with core network
  - Virtualization software corresponding to platform capability, also compatible with core
  - Measurement software for unified PHY/MAC/network statistics for each expt
  - Separate management interface for remote monitoring and control
GENI Implementation: Wireless Subnets
– Overall Wireless Deployment Plan

- Six types of experimental wireless networks planned – necessary to support full range of protocol research and to enable new applications
  - 1. Wireless emulation and simulation (repeatable protocol validations)
  - 2. Urban 802.11-based mesh/ad-hoc network (real-world networking experience with emerging short-range radios)
  - 3. Wide-area suburban network with both 3G/WiMax (wide area) and 802.11 radios
  - 4. Sensor networks (…application specific, specific system TBD via proposal process; may include environmental, vehicular, smart spaces, etc.)
  - 6. Wireless networks as infrastructure using radio routers and both long/short-range (WiMax, 802.11) radio (…seamless integration of wired & wireless layer 3 protocols)
  - …also some common network facilities such as location & dynamic binding services

- Each network at a different geographic location – new spectrum allocation may be needed at some sites
GENI Implementation: Wireless Sub-Networks Overview

GENI Infrastructure

1. NSF Radio Testbeds
   - Protocol & Scaling Studies
   - Emulation & Simulation

2. Ad-Hoc Mesh Network
   - Broadband Services, Mobile Computing

3. Open API Wide-Area Networks
   - “Open” Internet Concepts for Cellular devices

4. Sensor Networks
   - Embedded wireless, Real-world applications

5. Emerging Technologies (cognitive radio)
   - Advanced Technology Demonstrator (spectrum)

6. Other services

- Location Service
GENI Implementation: Wireless Sub-networks – 1. NSF Testbeds

- Large-scale emulators and simulators provide important protocol testing capabilities when connected to GENI
  - Enables end-to-end protocol tests with large numbers of nodes
  - Reproducible experiments with extensive data collection; virtualization per experiment
  - Cost ~$1-3 M per testbed for control/management upgrade and integration

Research Focus:
1. Protocol validation for next-gen wireless
2. Scalability experiments (ad-hoc, sensor)
3. Hybrid networks with multiple radio PHY
4. End-to-end transport for mobile devices
5. Controlled mobility experiments

- Ad-hoc wireless network providing full coverage of high-density urban area ~ 10 Km**2
  - Enables experimentation with mesh network protocols & broadband mobile applications
  - Dual-radio forwarding node as building block
  - Open API 802.11 with soft MAC, virtualization by frequency or space
  - Services for running expts, data collection, frequency assignment and spectrum meas
  - Capital cost ~$10M for ~1000 nodes (30x30) with power, some with fiber/VDSL (note: does not include software; significant operating cost for bandwidth and maintenance!)

**Research Focus:**
1. Ad-hoc routing
2. Self-organization & discovery
3. Cross-layer optimizations
4. MAC layer enhancements
5. Security with ad-hoc routing
6. Broadband QoS
7. Impact of mobility
8. Real-world application studies
3. Open API Wide Area Mobile Network

- Open API wide-area wireless network to explore alternatives to cellular, hybrids with WLAN, Infostations, new mobile applications…
  - Suburban coverage ~50 Km**2 using ~10 wide-area BTS’s + ~100 short-range AP’s
  - Open API 3G or WiMax BTS and dual-radio 802.11 node as building blocks
  - Capital cost ~$5-10M for BTS/tower and AP with fiber/VDSL (note: does not include software; significant operating cost for bandwidth and maintenance)

Research Focus:
1. Internet transport for 3G/cellular
2. Mobility support in future Internet
3. Hybrid 3G/WLAN handover, etc.
4. Multicasting
5. Transport layer for wireless
7. Information caching and multimedia

- Propose to build advanced technology demonstrator of cognitive radio networks for reliable wide-area services (over a ~50 Km**2 coverage area) with spectrum sharing, adaptive networking, etc.
  - Basic building block is a cognitive radio platform, to be selected from competing research projects now in progress and/or future proposals
  - Requires enhanced software interfaces for control of radio PHY, discovery and bootstrapping, adaptive network protocols, etc. – suitable for protocol virtualization
  - New experimental band for cognitive radio (below 1 Ghz preferable)
  - Cost for ~50 Km**2 deployment based on ~50 CR network nodes (AP’s or FN’s) + ~500 CR terminals (client modules) – estimated capital ~$7.5M (high due to early stage of technology curve; does not include significant NRE, software or operations cost)

Research Focus:
1. New technology validation of cognitive radio
2. Protocols for adaptive PHY radio networks
3. Efficient spectrum sharing methods
4. Interference avoidance and spectrum etiquette
5. Dynamic spectrum measurement
6. Hardware platform performance studies

- 2-3 sensor network projects to be selected via proposal process in view of application-specific nature
  - Sensor network experiments will leverage 802.11 mesh or 3G wide area infrastructure in items 2,3
  - Provide “user deployment kit” with platforms including sensor nodes and sensor/WLAN or sensor/3G gateway
  - Incremental capital cost per sensor net scenario estimated at ~$1M based on ~1000 sensors and ~100 GW’s

Research Focus:
1. Sensor network protocols – data aggregation, power, etc.
2. Scaling and hierarchies
3. Information processing in sensor nets
4. Platform hardware/software optimization
5. Real-time, closed-loop sensor control applications
6. Vehicular, smart space and other applications

Note: further details of 2-3 candidate sensor net application scenarios to be provided later

- Wireless testbed to be developed with focus on use of radio links and routers as core network infrastructure
  - Basic building blocks are wide-area radio module (3G, WiMax), directional antennas and radio router
  - Wireless used to provide regional core network connecting to tier 1 POP’s
  - ~20 radio routers including ~5 wired gateways
  - Capital cost ~$10-20M (note: does not include significant software, access bandwidth and operations costs)
  - Will require experimental license in UMTS or similar band

Research Focus:
1. Use of MIMO/directional radios and WiMax for Internet core
2. Super high-speed wireless data link protocols
3. Self-organization and network topology adaptation
4. Integration with wired network protocols
5. Spectrum efficiency studies
6. Comparison with wired network solutions for robust/ or emergency infrastructure applications
GENI Implementation: Wireless Network Development & Deployment Schedule

Schedule assumes 5-yr network rollout period

Major milestones:

- **Year 1:**
  - Integrate existing wireless testbeds with PlanetLab, GENI core
  - Finalize designs and implementation plans for proposed wireless subnets
  - Procure or develop sensor and 802.11 radio modules and platforms

- **Year 2:**
  - Start construction of 3 new testbeds (ad-hoc mesh, 3G wide-area, sensor)
  - Complete development of 3G/WiMax radio modules and platforms

- **Year 3:**
  - Ad-Hoc Mesh and 3G Wide-Area testbeds complete
  - 2-3 Sensor networks deployed
  - High-performance radio router platform completed

- **Year 4:**
  - Infrastructure radio network testbed completed
  - Cognitive radio platforms, software and measurement infrastructure completed

- **Year 5:**
  - Cognitive radio network fully deployed

…firm schedule needs further discussion and coordination with other GENI groups