



# An actually global Internet?

## Reaching the Next Five Billion

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**Internet Innovations Workshop**

June 19-20, 2007

# Grameen Telecom



- ★ 'Village Phone' is a unique idea that provides modern telecommunication services to the poor people of Bangladesh.
- ★ So far over 95,000 loans of average US\$200 have been given to buy mobile phones.
- ★ Covers 50,000 of the 68,000 villages
  - 60M users
  - => Scales!
- ★ Phone Lady income goes up by >2x
  - Maintains the system
  - => Works!
  - Example of new rural income

# Fantastic but misleading...

- ✱ Bangladesh is not actually rural !
  - ✱ 150M people in ~ Iowa
- ✱ Worse, no rural basestations
  - ✱ Villages are covered by *urban* basestations
    - Or those for major road/rail lines...
- ✱ Cellular is an URBAN success story...
  - ✱ We need a new story for rural coverage...
  - ✱ (China is the other exception... by decree)

# The Real Divide

- ✦ ... is not about developing countries
  - ✦ It is the rural/urban divide
- ✦ Urban net needs are converging worldwide
  - ✦ The world is "flat" only if you just look at cities
  - ✦ Fiber, cellular, WiMAX, data centers, etc. make sense for all major cities
- ✦ It is the rural needs that are unmet

# Default strategy...

- ☀ Basestations with “circular” blanket coverage
  - ☀ Cellular, GPRS, EVDO, WiMAX...
  - ☀ Expensive basestations => minimum user density
    - ... and minimum population density
- ☀ Solutions:
  - ☀ New low-cost (low capacity?) basestations
  - ☀ Change the service model or the blanket coverage...

# Three Rural Approaches

- ☀ Intermittent networking (DTN)
  - ☀ Non real-time model
  - ☀ Back to store and forward?
- ☀ Long-distance Point-to-point
  - ☀ Non-blanket model
  - ☀ Currently based on WiFi
- ☀ Satellites
  - ☀ Great coverage but historically expensive
  - ☀ New variations?

# Intermittent Networking

- ✦ Developing-region networks rarely connect end-to-end
  - ✦ Power, weather, reliability issues
  - ✦ Sometimes *intentionally* intermittent:
    - Low-earth orbit satellites: connect only while they are overhead
    - “Mules” – moving basestation collects data  
Basestation could be on a bus/motorcycle (DakNet)
- ✦ Internet and telephone networks assume end-to-end...
  - ✦ ... but asynchronous is often sufficient!
  - ✦ Clearly fine for e-mail and voice mail...
- ✦ “Delay-tolerant Networking” Research Group
  - ✦ New RFC
  - ✦ dtnrg.org, led by Kevin Fall

# Delay-Tolerant Networking

- ★ DTN: routing and storage for messages
- ★ DTN Pros:
  - **Cost**: better use of resources, more tolerant of problems
  - **Reliability**: delay hides transient problems
  - **Ease of deployment**: can be more ad hoc, less coordination than a synchronous system
  - **Coverage**: Intermittent coverage >> full time coverage
- ★ **Not really interactive**, or only interactive in some areas
- ★ TierStore: Storage infrastructure on top of DTN
  - Supports e-mail, v-mail, web proxy, data collection apps, broadcast
  - Claim: Very low cost per user

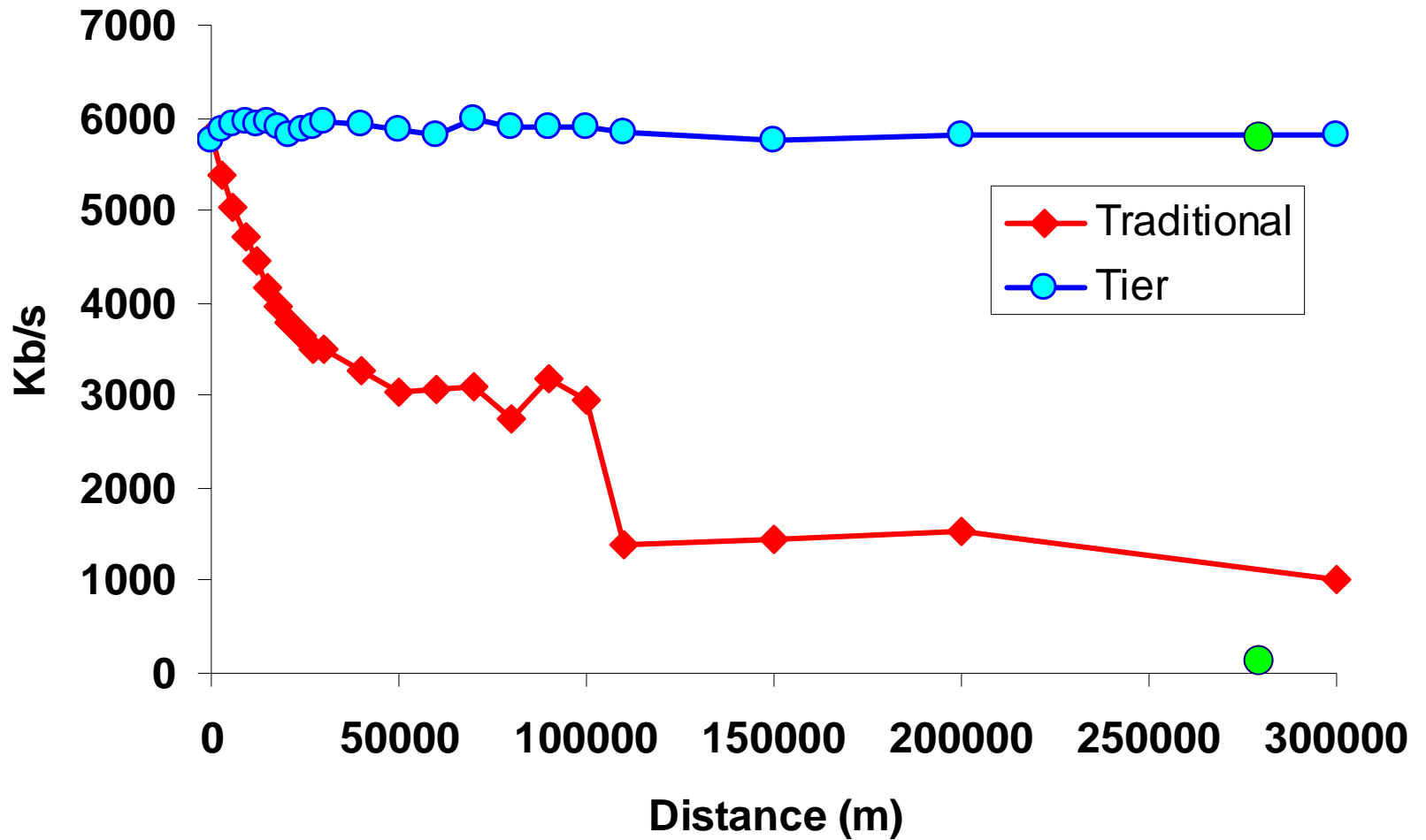
# Long-distance point-to-point

- ★ Goal: low cost 50+ km links (\$300?)
- ★ Exploit \$5 802.11 chipsets
  - ★ ... but need new network stack (MAC+)
- ★ Low power as well (e.g. solar)
- ★ Longer term:
  - ★ Low-cost antenna arrays
  - ★ Can migrate to fiber on demand

# Slotted WiFi MAC

- ☀ Move to TDMA with coarse slots
  - ☀ Rate-based flow control (due to high RTT)
  - ☀ Exponential backoff is bad for voice
- ☀ Move to bulk acks
  - ☀ Turn off automatic acks
  - ☀ Normal ack timeouts too short
- ☀ Need to fix TCP performance
- ☀ Support multiple antennas per pole
  - ☀ "burst synchronization" => all send or all receive
  - ☀ Turn off carrier sense (to co-transmit with neighbor)

# Bandwidth vs Distance



# Tier WiFi Results so Far

- ★ Several deployments
  - 7-link testbed in Berkeley
  - 5 links in Ghana for education
  - 9 in India for telemedicine
  - 2 in Guinea-Bissau for community radio
- ★ Longest: 284 km link in Venezuela
  - 6 Mb/s (3 Mb/s TCP in each direction)
  - Attempting 380 km in July (new World Record)
- ★ Best BW: 18 Mb/s in Berkeley (11g)
  - 4-6 Mb/s TCP typical for 11b
- ★ 7W power at full duty cycle
- ★ Cost is about \$400 per node in low volume

# Rural Telemedicine



- ☀ Aravind Eye Hospitals
  - Tamil Nadu, India
  - 5 hospitals
  - But too far for most to walk
- ☀ Need:
  - 15M blind in India
  - 70% of blindness treatable
  - 7% in rural areas get care
- ☀ Goals:
  - 50 rural vision centers
  - Diagnosis and prevention





20,000  
Real  
Patients



# Satellites: Move to LEOs

- ✦ Much of the world's rural population only reachable by satellites
- ✦ Geostationary satellites are too expensive
- ✦ LEOs: (Low-earth Orbit)
  - ✦ Are cheaper to build and launch
  - ✦ Can and have been built by students
  - ✦ Interesting network for architectural experimentation
  - ✦ Even just equatorial satellites would cover many new users!

# What are PICOSATS/CUBESATS?

- ✦ Picosats are a class of satellites defined by *size*
- ✦ Cubesats:
  - ✦ 10cm cube, commercially available Picosat
  - ✦ \$5k for sat kit, can be combined up to 3x size
  - ✦ Larger size: more battery/sensors/propulsion
  - ✦ <http://www.cubesatkit.com>
  - ✦ <http://www.cubesat.info>

# A Cubesat Kit



(C) Copyright 2003 Pumpkin, Inc.

# A Cubesat Launcher

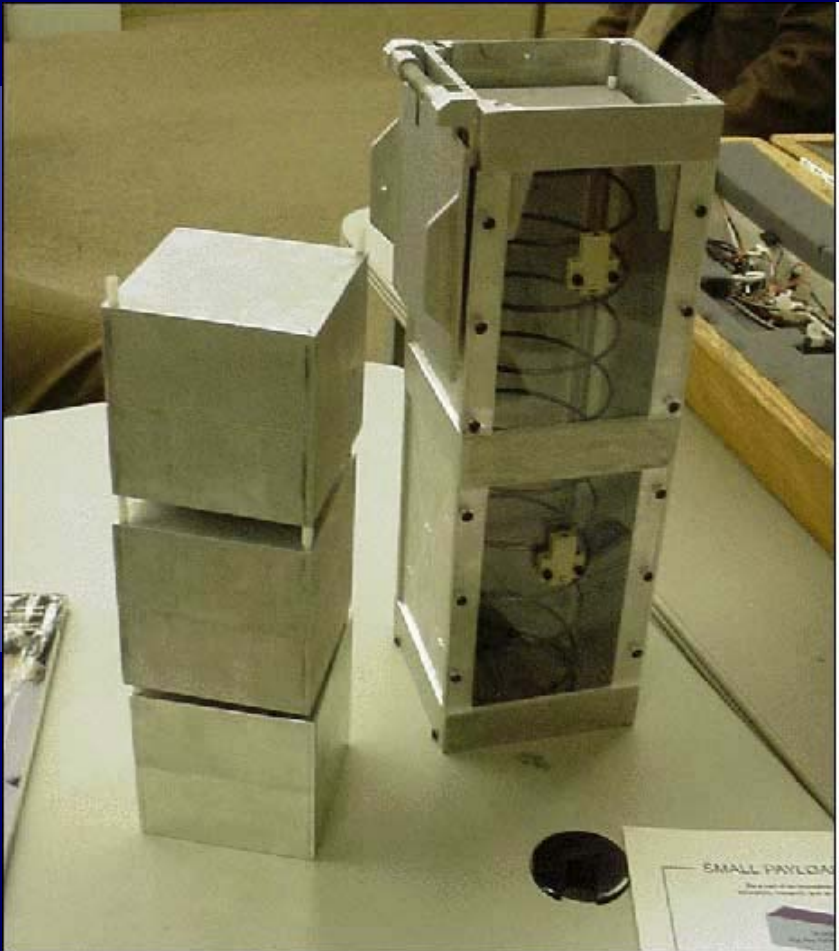


Photo: Stanford University



DNEPR Rocket  
(converted SS-18)

# Cubesat capabilities

- ★ 10cm x 10cm x 10cm cube; 1kg payload
- ★ Sensors
  - gravity, magnetometry, upper atmosphere meteorology, imaging
- ★ Communications
  - Store-and-forward while over ground stations (so far)
    - DTN revisited...
  - Sat-to-sat comms possible but challenging

# Picosat Network Costs

- ★ Russian launch: \$150K (up to 3)
  - ★ (but a recent offer to do so 'for free')
- ★ Budget ground station: ~\$1k
- ★ Cubesats: \$5k each
- ★ Roughly a dozen in orbit already...

# Three wide-open areas...

- ✦ How to make store-and-forward really work...
- ✦ How to connect remote villages/schools/clinics?
- ✦ How to exploit LEO satellites?
  
- ✦ Many research issues:
  - ✦ Core architectural issues: routing, fault tolerance, storage, time variation....
  - ✦ Everything up to transport layer...
  - ✦ Remote management!

# For more details....

- ★ Overview:

- “The Case for Technology for Developing Regions” – E. Brewer *et al.*

- ★ IEEE *Computer*, June 2005

- ★ [Tier.cs.berkeley.edu](http://Tier.cs.berkeley.edu)

- ★ [dtnrg.org](http://dtnrg.org)

# Cubesat status

- ✦ Globally, Cubesat kits have been built by engineering students at universities in 21 countries
- ✦ A global network of ~20 Cubesat downlink stations exists
- ✦ There are two annual small satellite conferences with international participation
- ✦ Roughly a dozen Cubesats are in orbit

# Cubesat / Picosat components

- 10-cm cubed metal frame
- Battery or solar power
- Software for positioning, comms, battery management
- Sensor payloads
- Launch vehicle (e.g. Russian spacecraft)
- Ground tracking/comms stations