Next Generation Wireless Networks: Research Challenges and Opportunities

Abhay Karandikar
Professor
Department of Electrical Engineering
Indian Institute of Technology Bombay, Mumbai 400076
karandi@ee.iitb.ac.in

Hari Om ashram prerit Dr Vikram Sarabhai award Lecture 2010
Outline

- Global Wireless Scenario
- Indian Scenario
- Key Research Issues and Technology Components of 4G
- Our Contributions to 4G
  - Bandwidth Request Procedure in IEEE 802.16m
  - Energy Efficient Scheduling over Wireless Channels
- Going Forward: Towards Bridging the Digital Divide
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### Drivers for Broadband

<table>
<thead>
<tr>
<th>Email</th>
<th>VoIP</th>
<th>Applications</th>
<th>Search</th>
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</thead>
<tbody>
<tr>
<td>Yahoo Mail, Gmail, Hotmail</td>
<td>talk, skype</td>
<td>Google Maps, horoscope.com</td>
<td>Google, bing, Yahoo!</td>
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<td>Social Communities</td>
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<td>Open Source</td>
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<td>Orkut, Facebook</td>
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<td>Free as in Freedom</td>
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<td>Peer-to-peer</td>
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<td>Audio/Video/Images</td>
<td>Real-Time games</td>
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<td>BitTorrent, YouTube, flickr</td>
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<td>zapak.com Beta</td>
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Plethora of services causing Internet traffic to grow 50% every year
Timelines for IMT-Advanced (4G)

2008: Proposals
2009: Evaluation
2010: Consensus
2011: Specification
2012: Early Deployment
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Indian Scenario

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Going Forward: Towards Bridging the Digital Divide
Scenario in India

- **600 Million Cellphone subscribers**
  - Second largest telecom market in the world
- **Fewer products made in India**
  - Large part is still imported
- **High outflow of Foreign Currency**
  - $15 royalty outflow per handset
- **Only country in the top telecom markets with no umbrella body focusing on standards**
- **Low Geographical Coverage**
  - Only 60% of India
  - 25% of villages covered
- **Very Low Broadband penetration**
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Technology Components for 4G

- **OFDMA**

- **Multi-Antenna (MIMO)**

- **Spectrum flexibility and Carrier aggregation**

  Aggregated carriers = 40 MHz
Technology Components for 4G

- Self organization and Self optimization
- Relaying

Enhanced Quality of Service support
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Going Forward: Towards Bridging the Digital Divide
Wireless Uplink Scheduling

BS computes non-conflicting schedule
Bandwidth Request (BR) Procedure

• AMS waits for a random number of BR Opportunities
• Number of BR opportunities to wait chosen from Contention Window
• Common channel for all AMS
Drawbacks of BR Procedure

- No differentiation
  - No differentiation in window size based on service class

- Lacks fairness
  - New users can get channel before old users

- Scaling factor of 2 is used independent of
  - System load
  - Number of retries
Our BR Proposal (IEEE C80216m-09_1321r4)

- **Connection Priority (CP)** for each contending Service Flow
- CP is a function of Service Class & Number of Retries (BR collisions)
- CP parameters:
  - Service Class
  - Initial / Maximum Window Size
  - Window Scaling Factor
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Going Forward: Towards Bridging the Digital Divide
Wireless Channel Characteristics

- Wireless Channel is characterized by
  - Signal strength variation over time, frequency and space
    - Small scale variation (Fading)
  - Interference
  - Limited battery life at hosts

- Physical Layer no longer a fixed rate bit pipe

- Resource allocation needs to take channel characteristics into account

Significant performance gains in wireless networks by Cross-Layer Design
SNR Fluctuations in a Multiuser System

The graph illustrates the signal-to-noise ratio (SNR) of three users over time. Each user is represented by a different line color:
- User 1: Black line
- User 2: Blue line
- User 3: Red line

The SNR values fluctuate over time, highlighting the dynamic nature of the system.
Multiuser Diversity: A New Form of Diversity

- Channel fades independently for each user so...
  - Different users experience different channel gains
- High probability that some user will have a strong channel
- BS schedules the user with the strongest (best) channel
- Hence ... “Opportunistic Scheduling”
- Transmitting in favorable channel condition also minimizes power but at the expense of delay
- Scheduling- Power is minimized subject to delay constraint
Rate-Power relationship is convex

\[ R_2 = 2R_1 \]
\[ P_2 > 2P_1 \]
Energy Efficient Scheduling

- Single Receiver (Base Station) and multiple transmitters
- Base station is the centralized scheduler
Energy Efficient Scheduling

- Queue transition, average queue length, average power for user $i$

\[ Q_{n+1}^i = Q_n^i - I_n^i R_n^i + A_{n+1}^i, \quad R_n^i \leq Q_n^i \]

\[
\bar{Q}^i = \limsup_{M \to \infty} \frac{1}{M} \left[ \sum_{n=1}^{M} Q_n^i \right]
\]

\[
\bar{P}^i = \limsup_{M \to \infty} \frac{1}{M} \left[ \sum_{n=1}^{M} P(X_n^i, I_n^i R_n^i) \right]
\]

- Problem: Minimize the power consumption of each user subject to delay constraint of each user

\[
\text{Minimize } \bar{P}^i \text{ subject to } \bar{Q}^i \leq \bar{\delta}^i, i = 1, \ldots, N
\]

- Multi-objective constrained optimization problem
Uplink Solution

- Visualize a link between user and base station as a Point-to-Point scenario
- Each user
  - Determines its transmission rate as if it was the only user
  - Informs this rate to the base station
- The base station schedules the user with the highest rate
- Queue transitions for a user who is scheduled and not for others
- Power and queue cost are appropriately updated
The base station auctions each time slot

The user quoting the highest rate wins the bid

User quote rates that are just sufficient to satisfy their delay constraints

Quoting unnecessarily high rates not favorable since power minimization is the objective

It can be proved that the queue lengths converge to cooperative equilibrium and delay constraints are satisfied

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Driving Research Agenda

**Backhaul connectivity**
Low cost wireless backhaul

**Low ARPU**
Low cost infrastructure
Tight integration with IP
Infrastructure sharing

**Challenges**

**DSL like experience**
Architecture for high speed
High speed spectral efficiency at cell edge

**Power Supply**
Very high energy efficiency
**Benefits**

- Inexpensive radio (<$50)
- Low power (<10 W)
- License free band
- But designed for Indoor

**Technical Innovation**

- Optimized MAC for outdoor point to point link
- Interference management for multi-hop link
- E1 circuit emulation for Legacy access GSM/CDMA

**Access & Devices**

- DSLAM
- WiFi
- UMTS/ HSPA
- GSM /EDGE

**Backhaul**

- TDM / ATM /ETHERNET

**Core**

- Edge Router

**Services**

- Voice
- Video
- Audio
- Packet switching
- Node
- Gateway

**Present Scenario**

- PSTN
- TDM/ ATM/ IP / MPLS
- Edge Router
- Internet
IP over Distributed Cellular Architecture

- **Present Scenario - Hierarchical**
  - Wireless access connect to packet core

- **Heavy Link Layer**
  - Handover and QoS at access
  - Network Discovery and topology between access and core
  - IP attachment at core
IP over Distributed Cellular Architecture

Wireless access network as IP network of base stations

Self Configuring Distributed Architecture

Base station cooperate to manage topology discovery

Mobility, QoS and network discovery managed at IP layer
Concluding Remarks

- India – one of the largest telecom market
- Indian requirements and IPR must get reflected into international standards
  - Significant opportunity to push our research into next generation wireless networks
  - This will catalyze manufacturing scenario in India
- We have outlined representative efforts
  - Bandwidth Request procedures for QoS in 4G
  - Energy Efficient Scheduling
- More efforts needed- academia and research labs need to address relevant research problems
Acknowledgements

Joint work with

Prateek Kapadia, Gauri Joshi, B Srinadh, Dr Nitin Salodkar. Prof Bhaskaran Raman (IITB), Prof Vivek Borkar (TIFR)

Funding support from TTSL-IIT Bombay Center for Excellence in Telecom (TICET)