
# Next Generation Wireless Networks: Research Challenges and Opportunities

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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

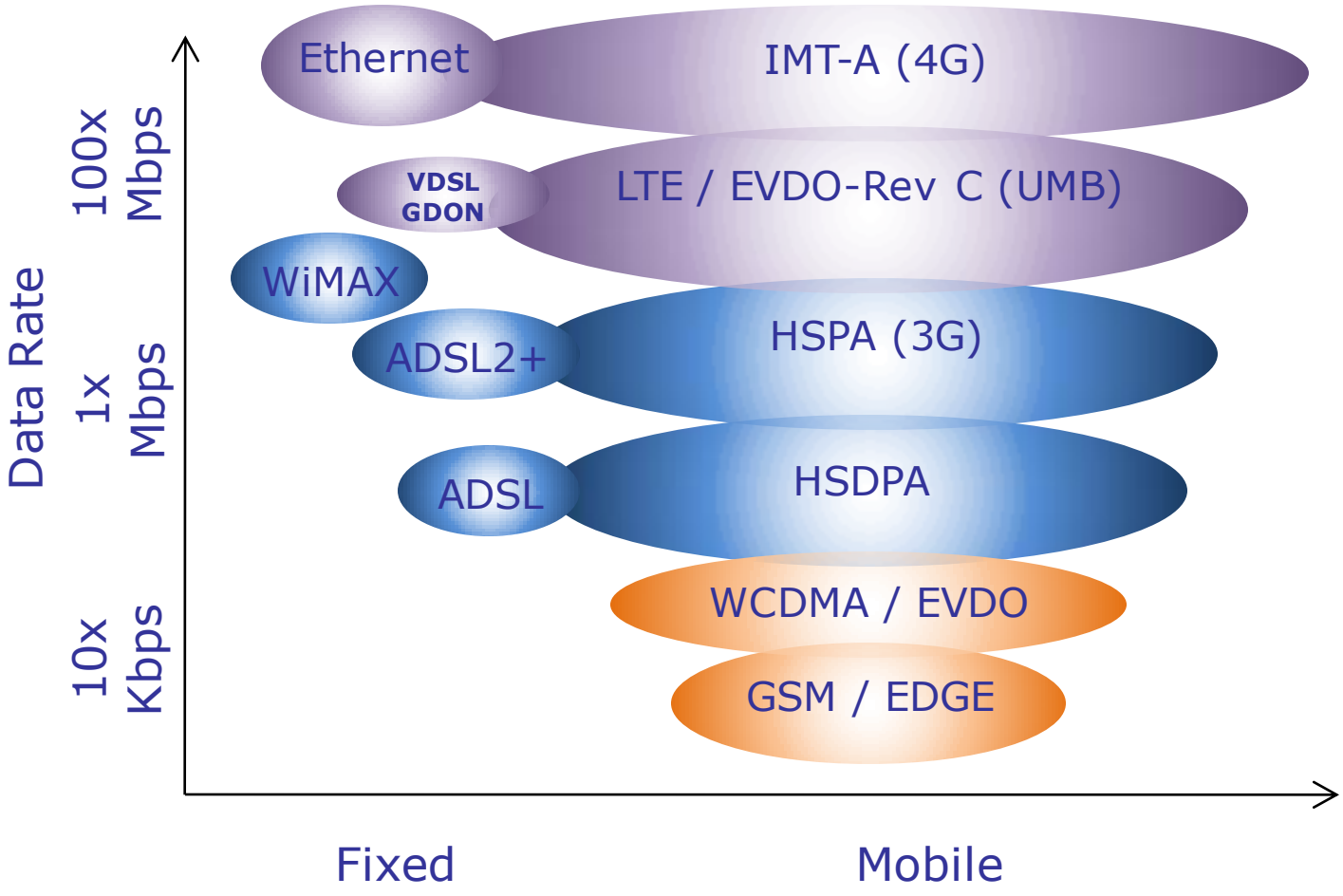
**Email** **VoIP** **Applications** **Search**

**Social Communities** **News** **Open-Source**

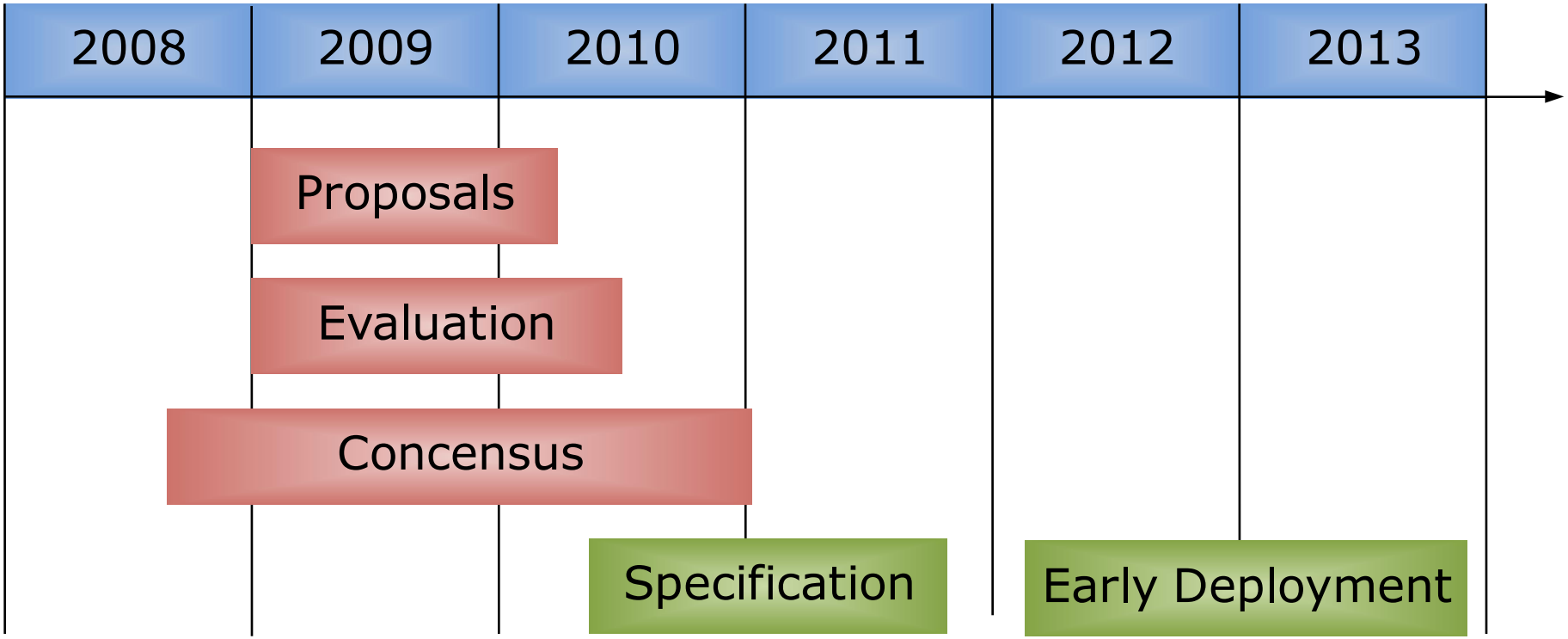
**Peer-to-peer** **Audio/Video/Images** **Real-Time games**

**Plethora of services causing Internet traffic to grow 50% every year**

# Wireless Broadband



# Timelines for IMT-Advanced (4G)



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# Scenario in India

**Population Density Map**
**(source: www.reliefweb.int)**

- 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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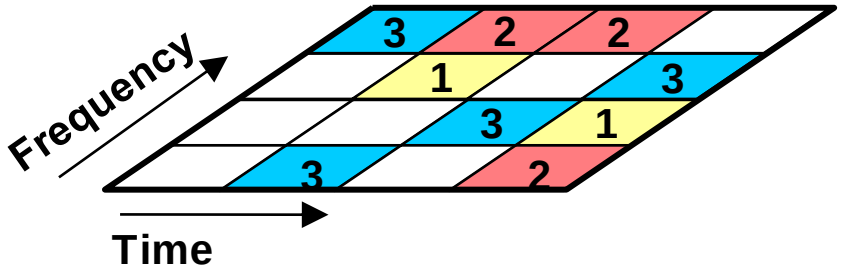
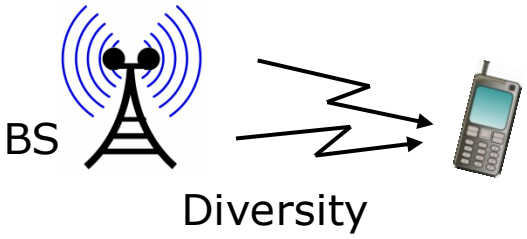
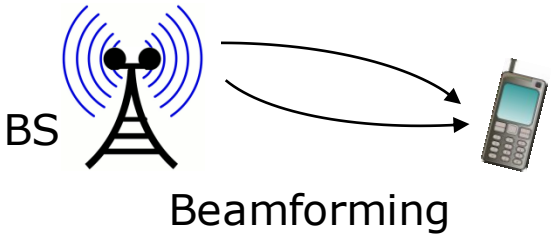
# Technology Components for 4G

- OFDMA

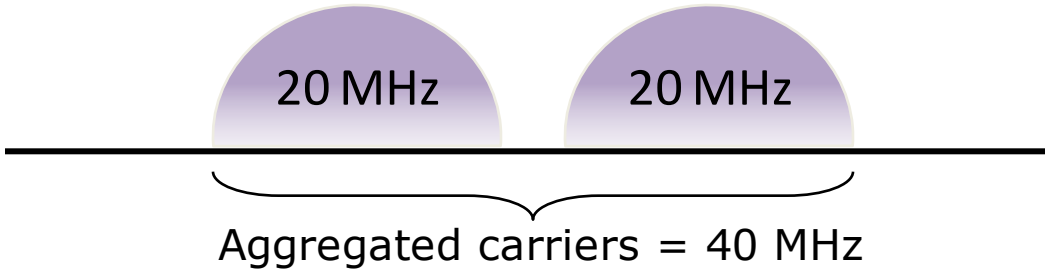



- Multi-Antenna (MIMO)



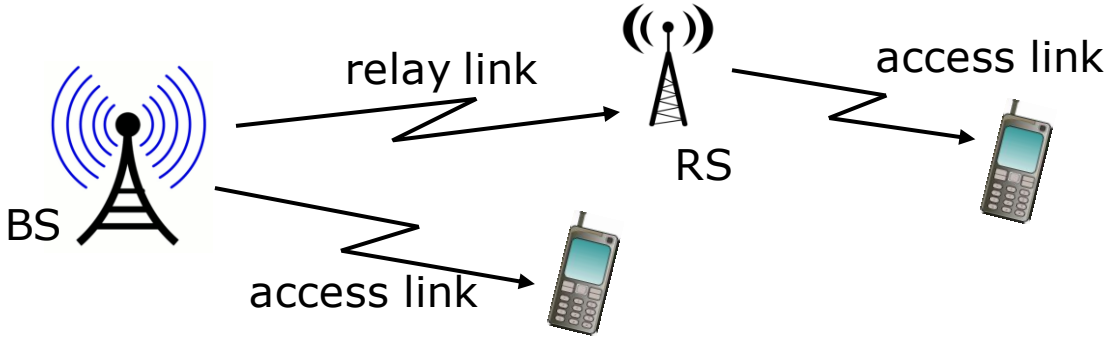




- Spectrum flexibility and Carrier aggregation

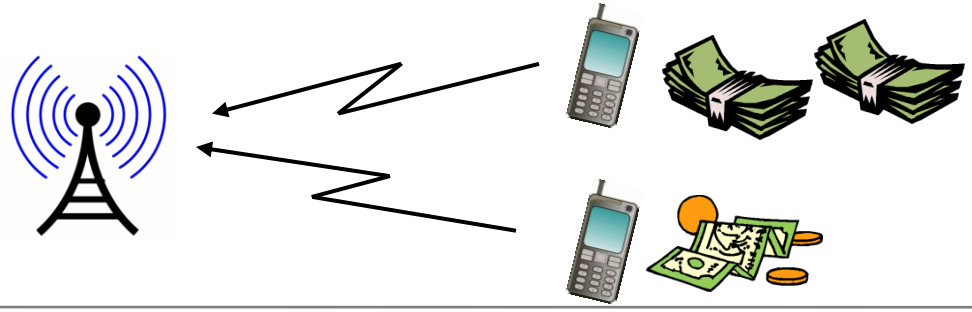


# Technology Components for 4G

- Self organization and Self optimization
- Relaying




- Enhanced Quality of Service support



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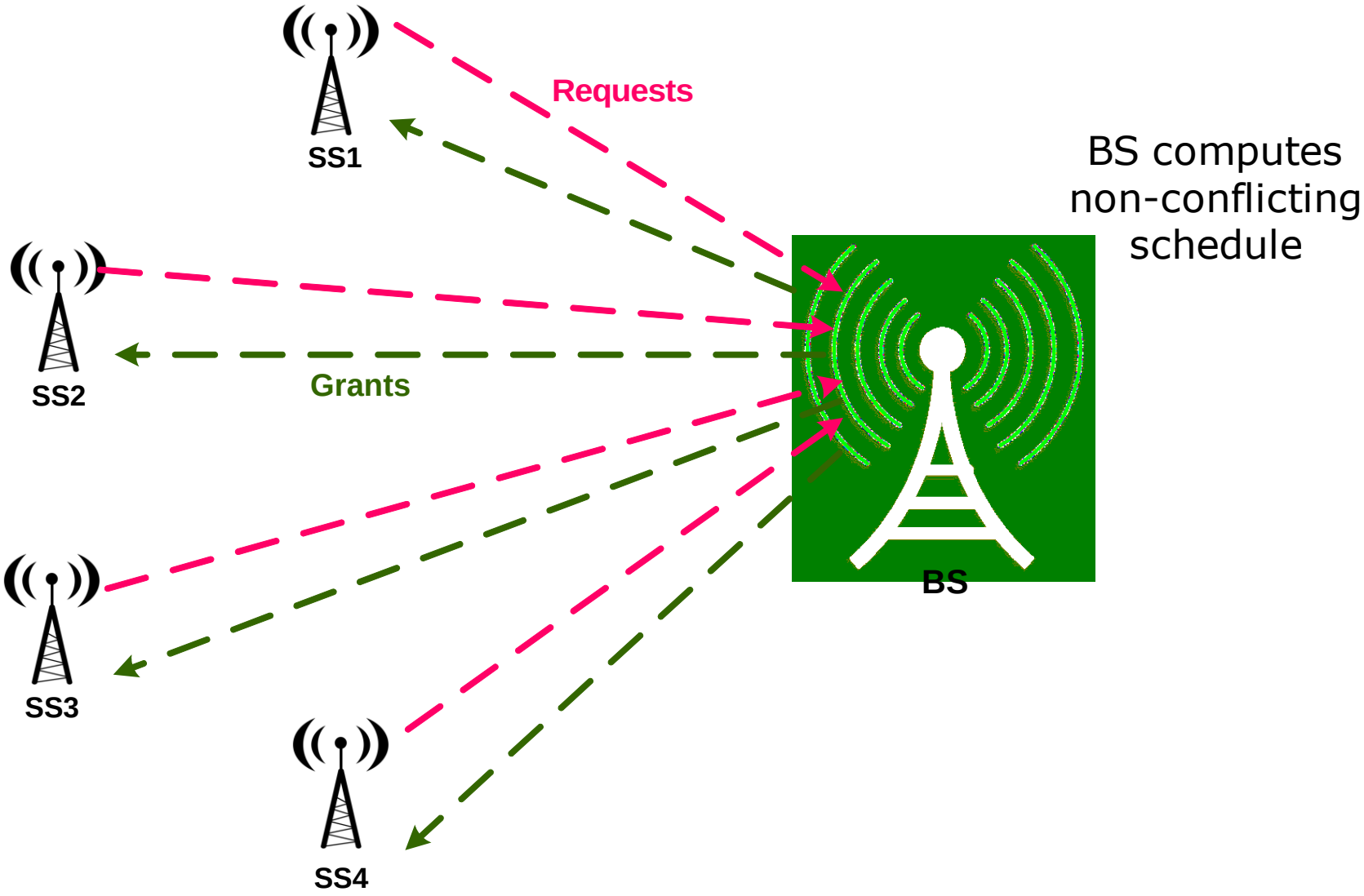
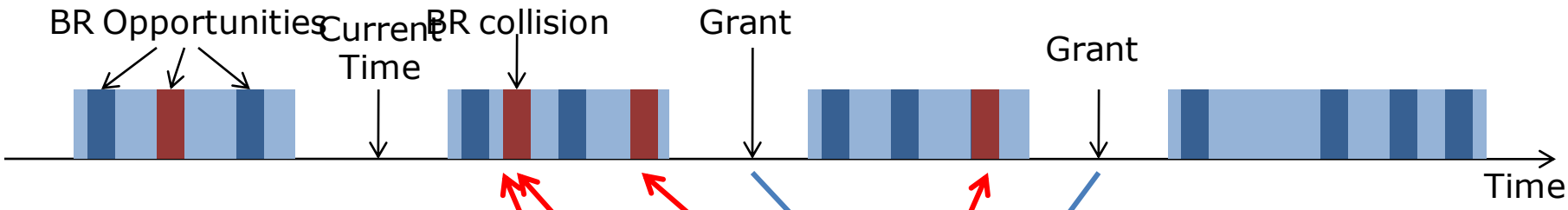
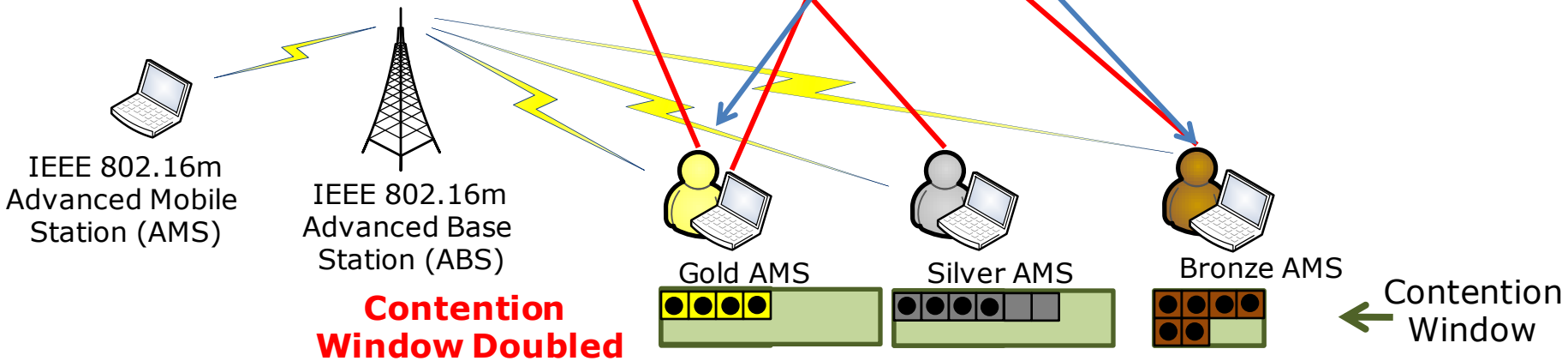
# Wireless Uplink Scheduling



# 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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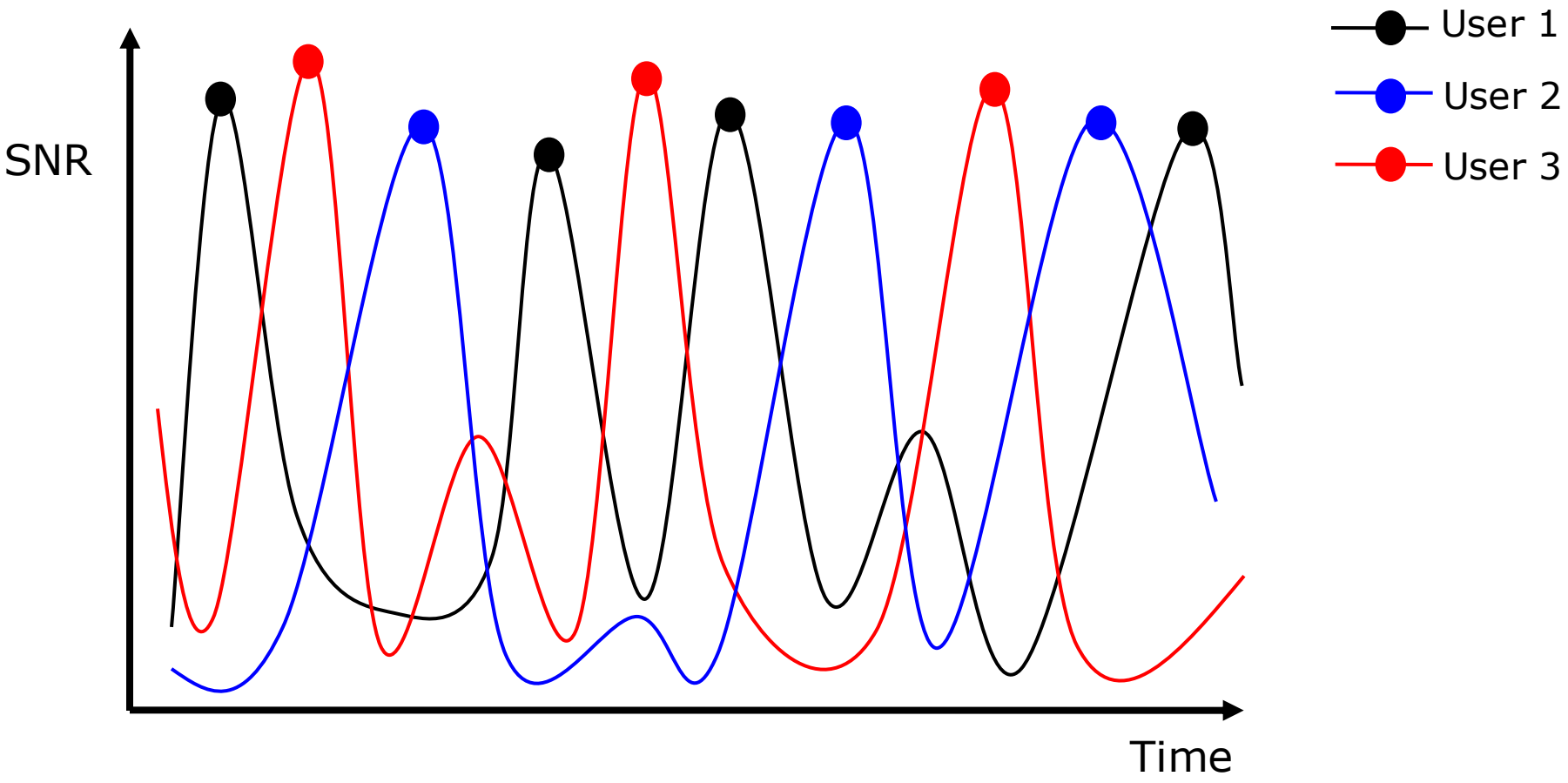
# Wireless Channel Characteristics

- 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

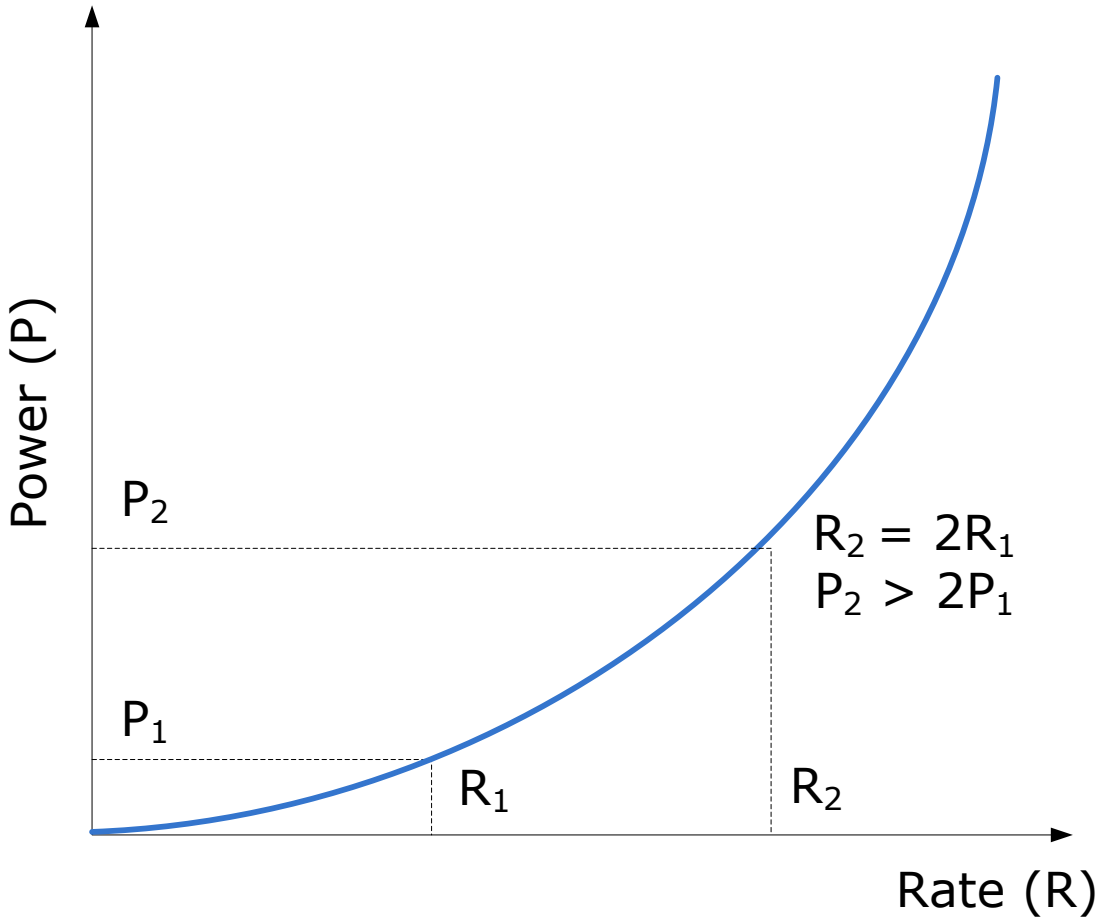


# Multiuser Diversity: A New Form of Diversity

- 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

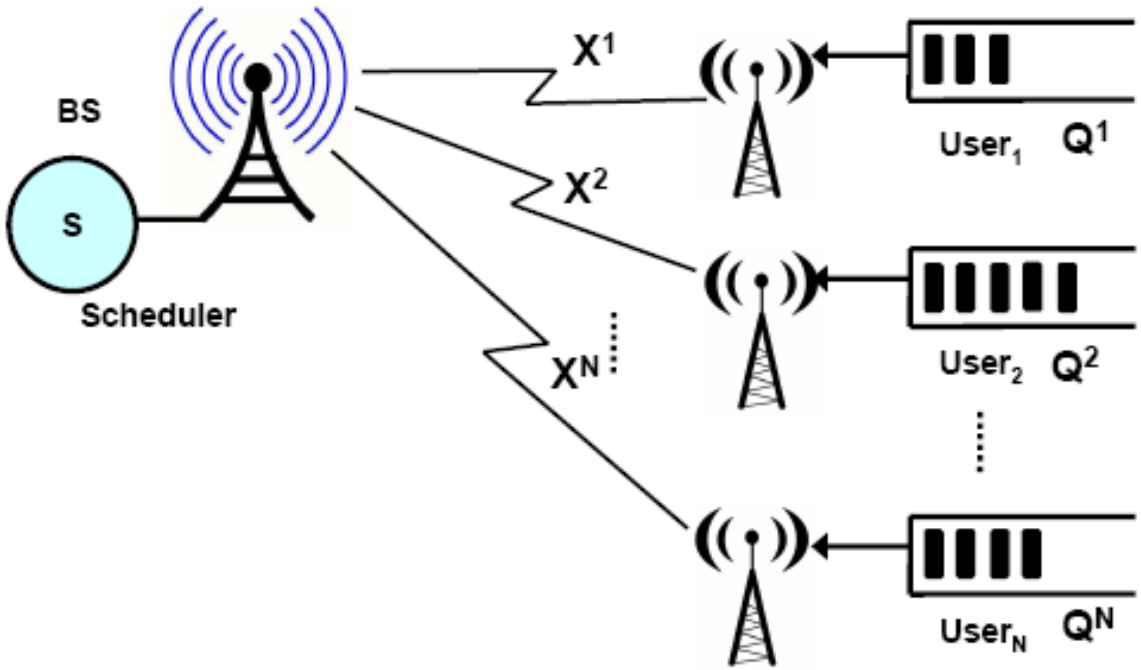
# Energy Efficiency

- Rate-Power relationship is convex



# 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*

$$Q_{n+1}^i = Q_n^i - I_n^i R_n^i + A_{n+1}^i, \quad R_n^i \le Q_n^i$$

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

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

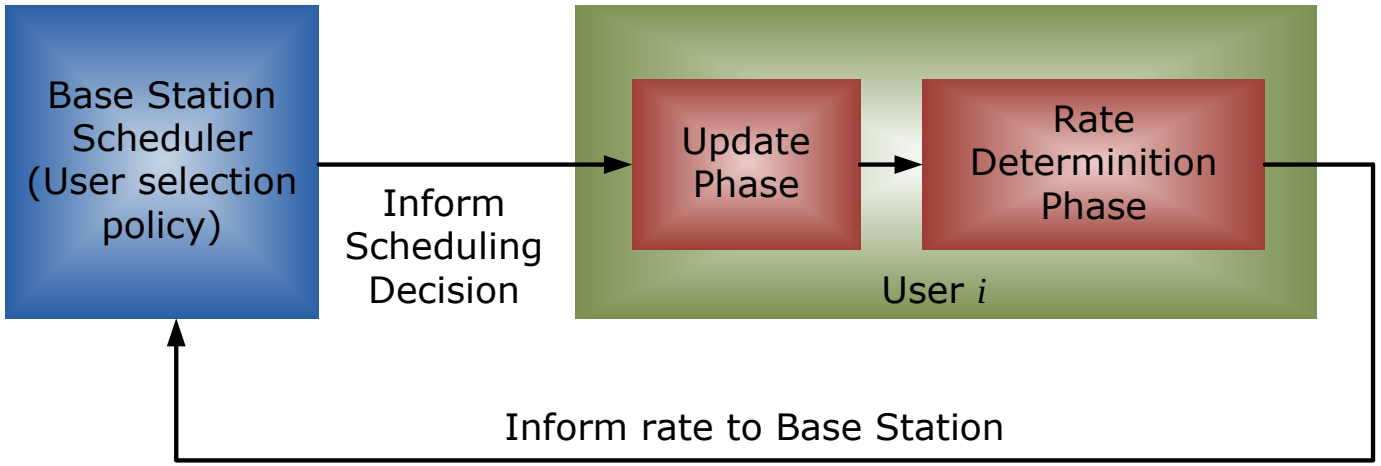
- Problem: Minimize the power consumption of each user subject to delay constraint of each user

$$\text{Minimize } \overline{P}^i \text{ subject to } \overline{Q}^i \le \overline{\delta}^i, i = 1, \ldots, N$$

- 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



# Uplink Solution : Auction Interpretation

- 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

Nitin Salodkar, Abhay Karandikar, Vivek Borkar, "A Stable On-line algorithm for Energy Efficient Scheduling" to appear in IEEE Transactions on Mobile Computing 2010

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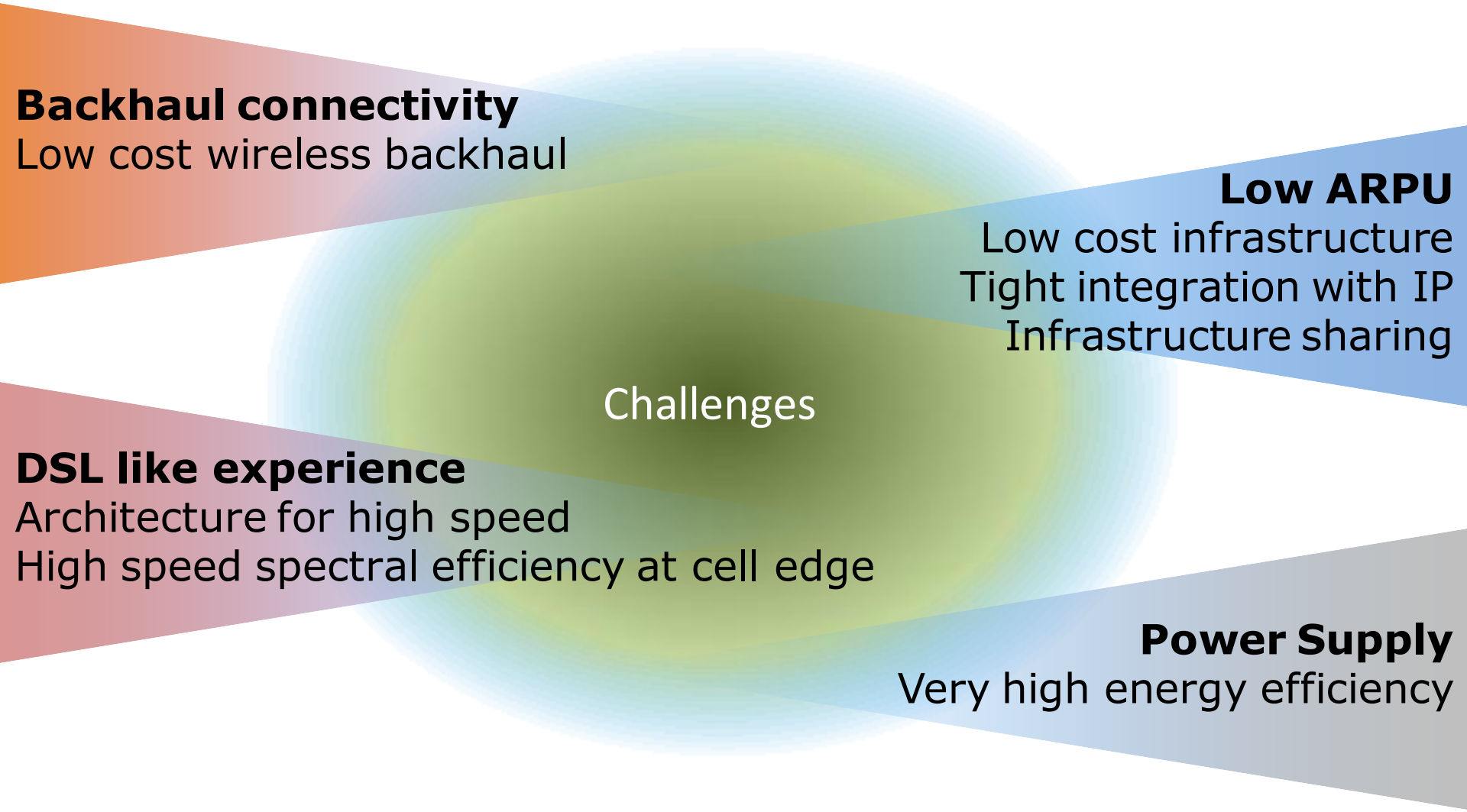
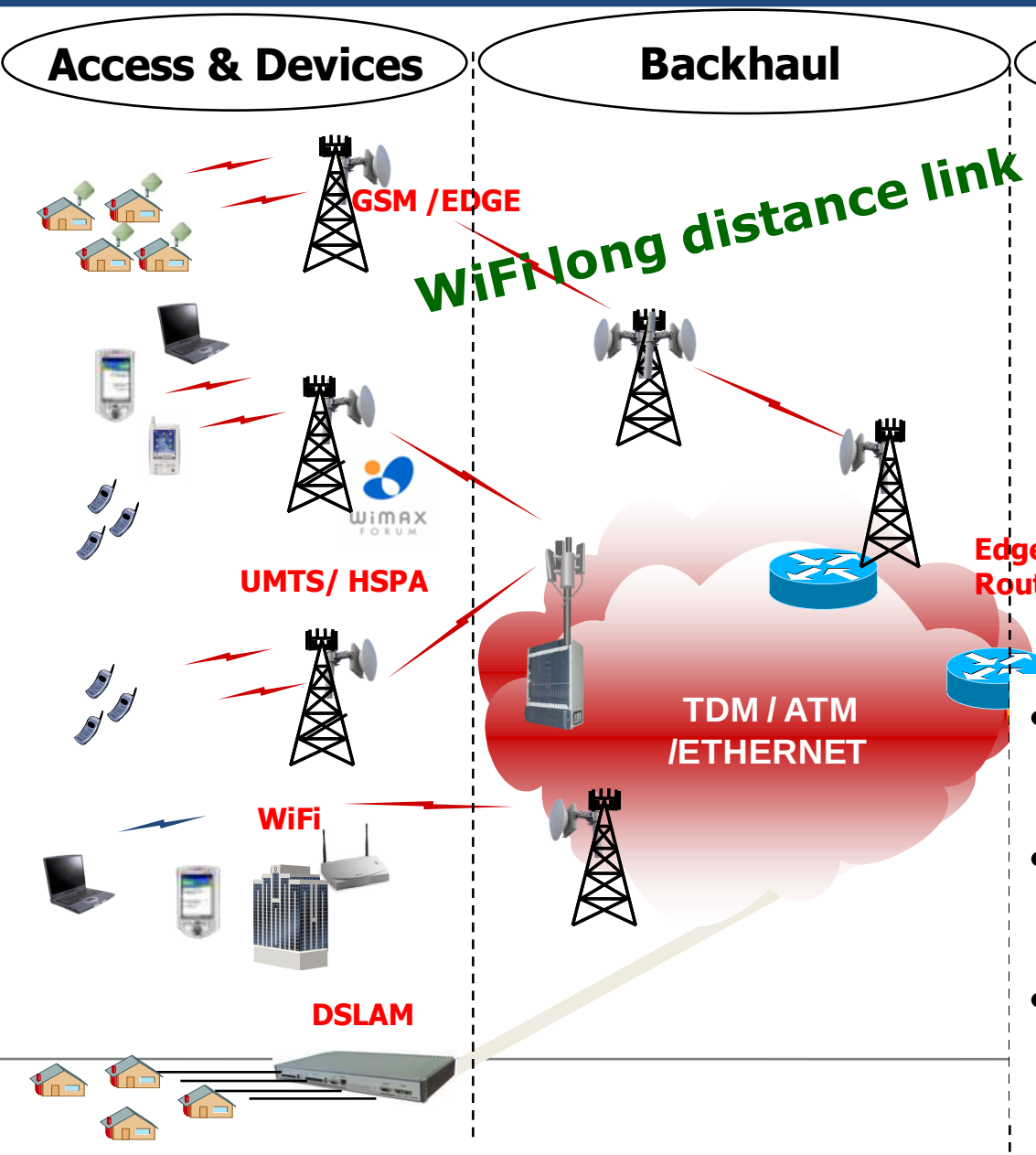
# Driving Research Agenda



# Backhaul




## Benefits

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

## Technical Innovation

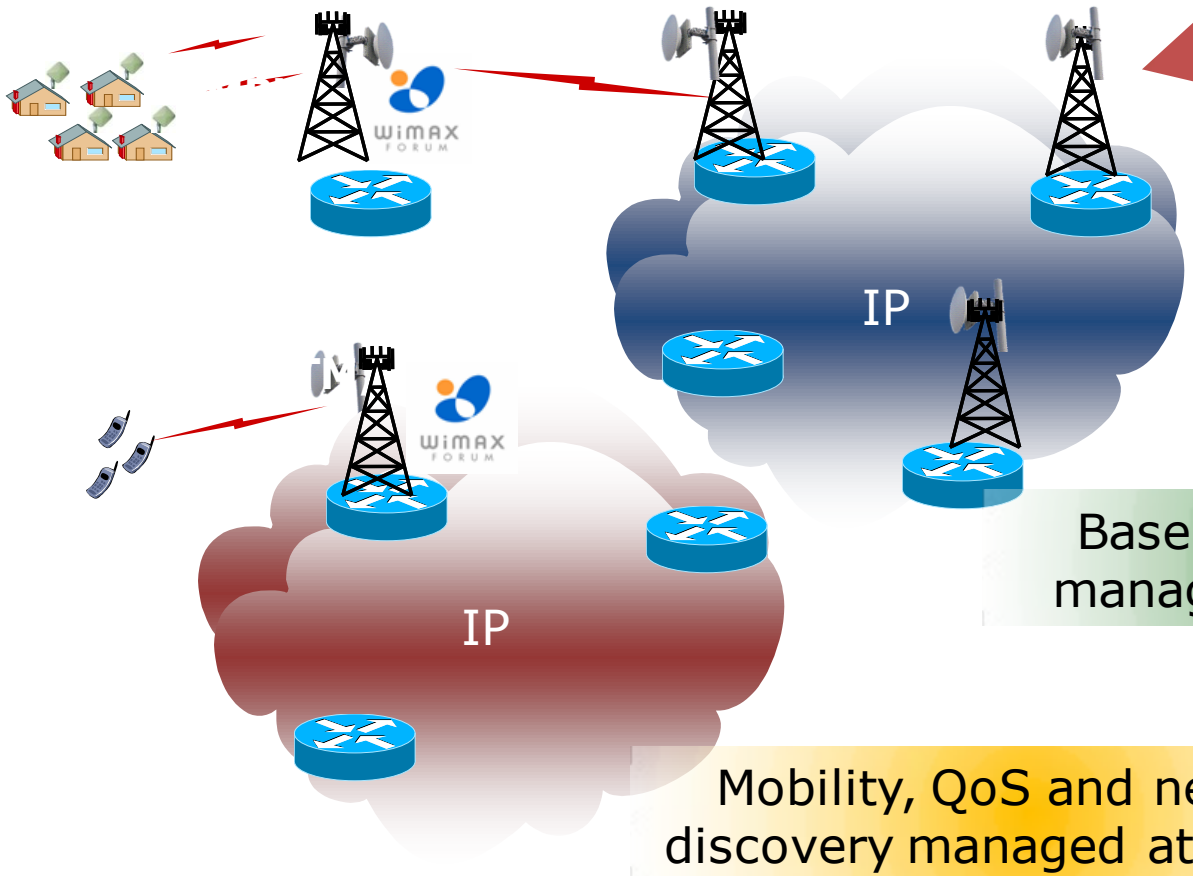
- Optimized MAC for outdoor point to point link
- Interference management for multi-hop link
- E1 circuit emulation for Legacy access GSM/CDMA)

# 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)