# Trends in Wireless Network Evolution

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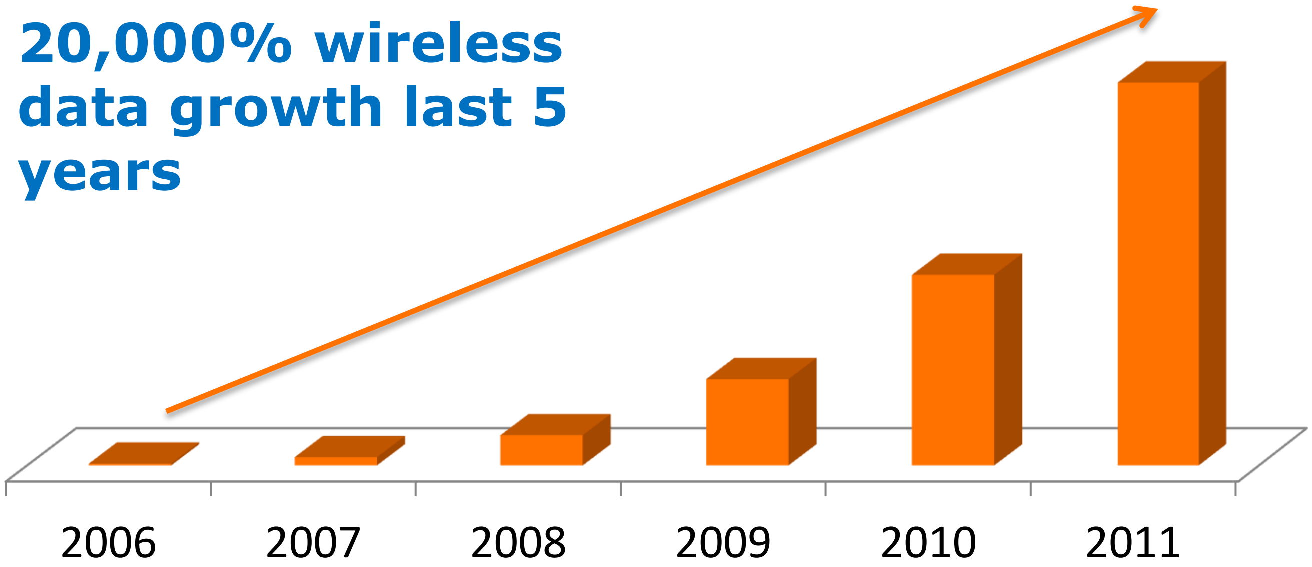
Rethink Possible®

# Drivers for Mobile Data Growth

**20,000% wireless data growth last 5 years**

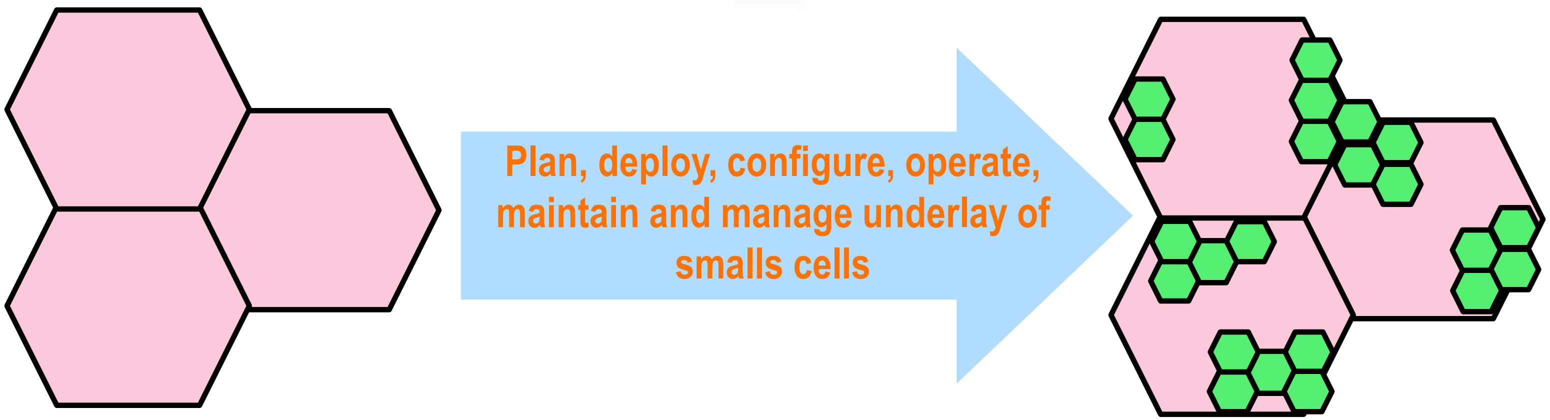



- Accelerating growth of mobile apps
- Higher speeds
- More powerful devices
- Increasing M2M communication

# Coping with Traffic Growth

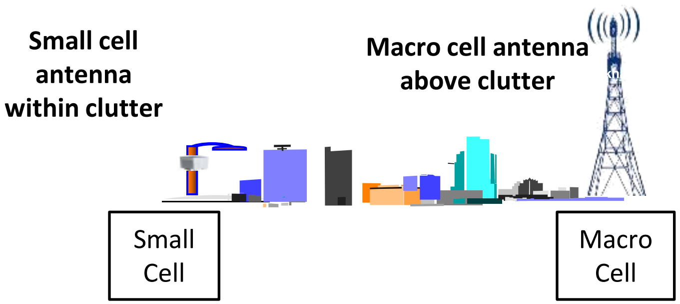
Available Spectrum

Traffic growth and mounting user expectations




- Small cells → Increase spatial reuse of existing licensed spectrum
- HetNets → Leverage unlicensed spectrum where possible
- Backhaul → Manage (dominant) cost of deployment
- Shared spectrum → New ideas for optimal use of spectrum (Agile and Cognitive Radio concepts)

# Science of Small-Cell RF Propagation




Conventional tools use Okumura-Hata model or its variants **Applicable for 150Mhz-3000Mhz and antenna heights 30m-1000m**

Small cells: much lower antenna heights and future radios may operate well beyond 3000 MHz

Need for better understanding of small cell RF propagation

## AT&T LABS RESEARCH INITIATIVES – Science of Small Cell RF Propagation

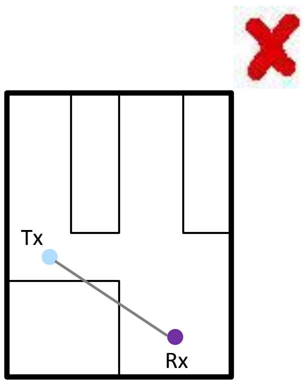
- New models for indoor and outdoor
  - Small cell RF behavior varies substantially between outdoor and indoor

    New models using actual field measurements, mathematical analysis, and simulations - to be incorporated into planning tools
- Exploration of a "no-model" approach with actual field measurements
  - May be a difficult task to model all RF propagation environments in the context of small cells - feed measurements directly into planning tools

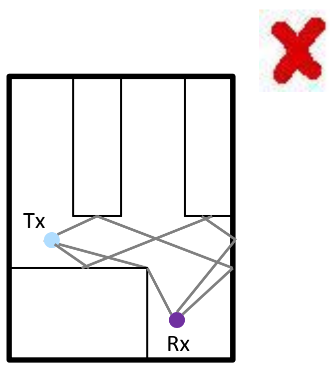
# Indoor Propagation Modeling

- Important modeling and implementation considerations
  - Acceptable accuracy
  - Minimum set of inputs
  - Low computational burden
  - Integration with supplementing RAN planning tools

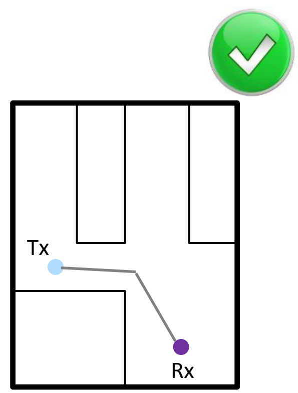
Dominant Path Model is recommended



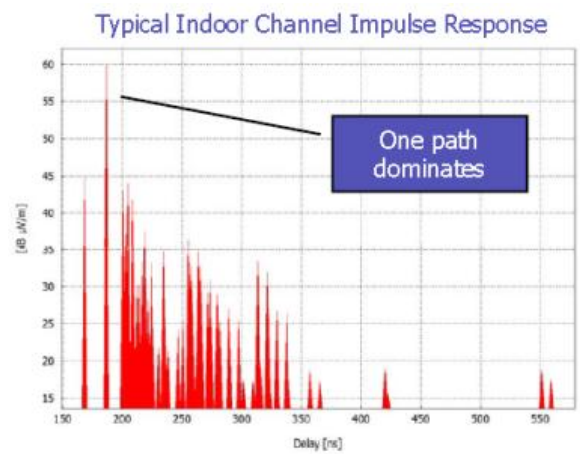

• One slope model




•3D ray tracing model




•Dominant path model

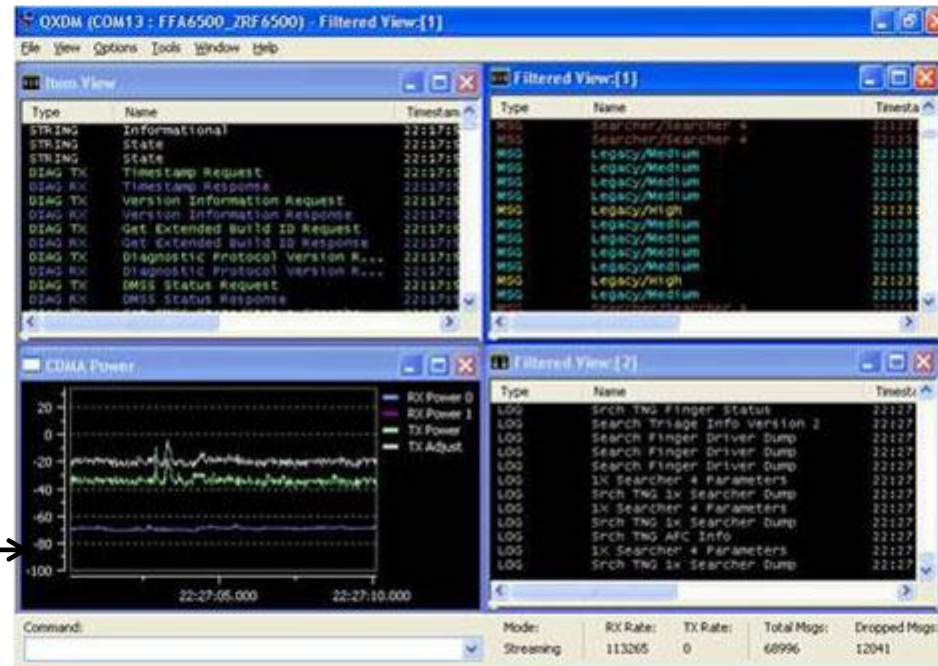



Key: Algorithm to derive dominant path

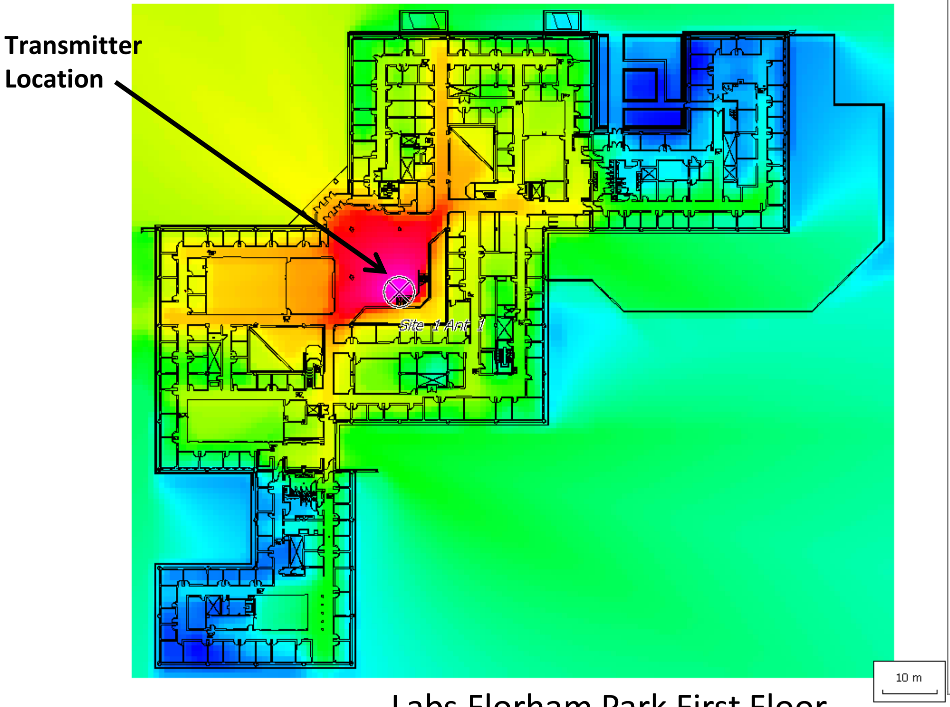
# Indoor RF Modeling Measurement Setup

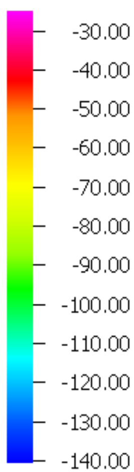
Transmitter:
AT&T 3G Microcell – 1900 MHz

Receiver: Phone (Samsung GSII) feeding Qualcomm QXDM software logging



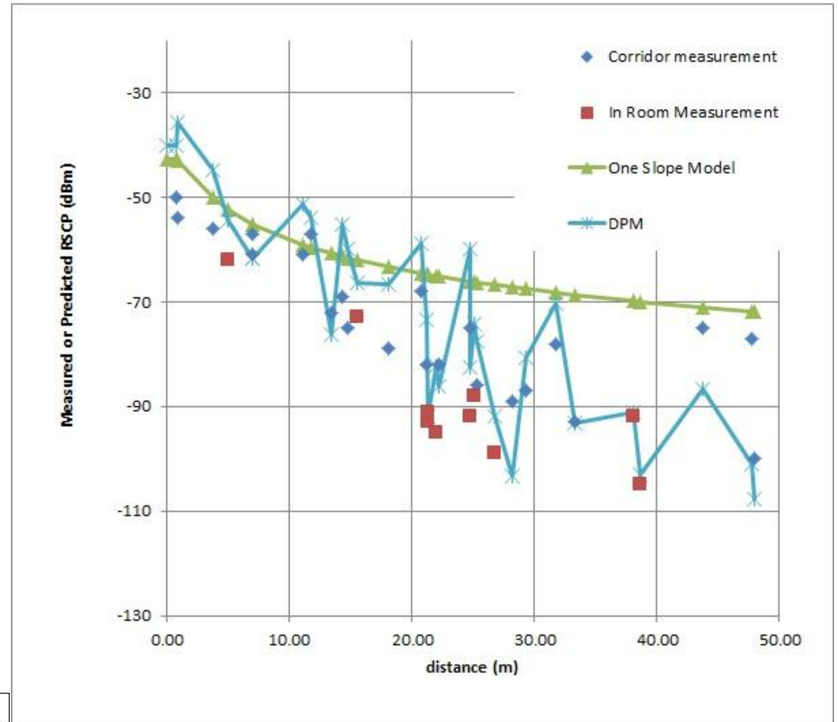
# Indoor RF Modeling: Sample Experimental Results: Venue – AT&T Labs, Florham Park, First Floor



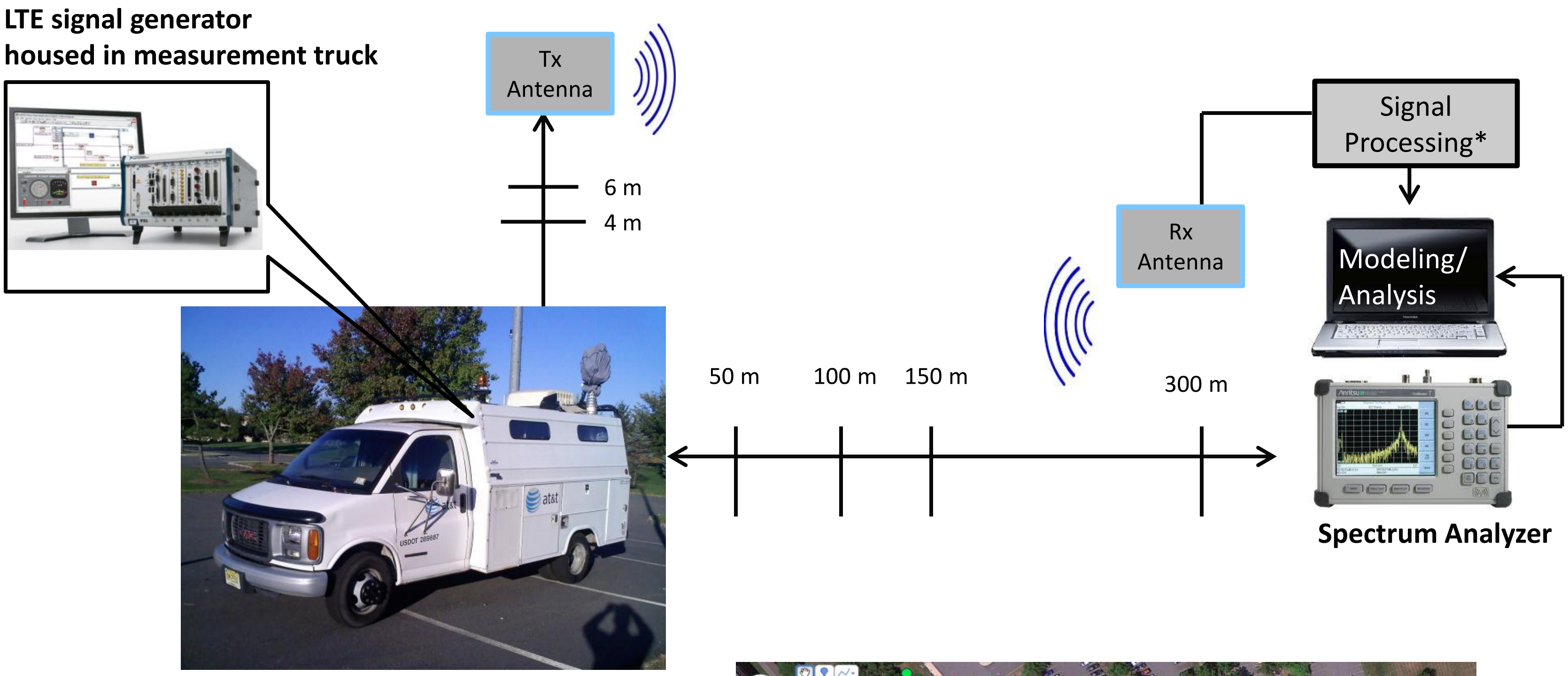

Labs Florham Park First Floor Coverage – Dominant Path Model

Received Power dBm




- Red squares indicate points inside rooms, while X's indicate corridor points
- Dominant Path Model follows inside- and outside-room trends which Single Slope model does not

# Outdoor Propagation Modeling – Target Dense Urban
## (In Progress)




**Measurement example**

**Labs Florham Park Parking Lot**


*Consists of software radio, low-noise amplifier, and down convertor

# Options for Backhaul

**Backhaul is the most significant cost component of small cell rollout**

- Need for optimizing backhaul

- Proper mix of technology (both conventional and unconventional) with supporting architecture

## Major Considerations

- **Native support of Ethernet**
- **Seamless integration with multiple access technologies**
- **Stable and accurate synchronization**
- **Low latency and jitter**
- **Ease of deployment and operation**
- **Scalability – decoupled from "N x" cost structure**
- **Reliability**
- **Use of sunken assets as much as possible**

## Some Options

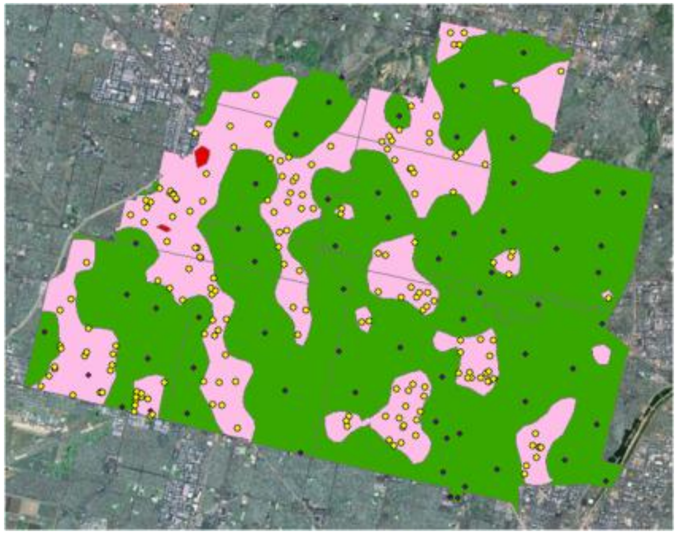
- **Fiber: PON and GPON**
- **Wireless – LOS and NLOS**
- **Terahertz and Free Space Optics**
- **Cable**

**Today:** **Fiber** is the best option; **microwave** is the next best; use **other options** when you have to.

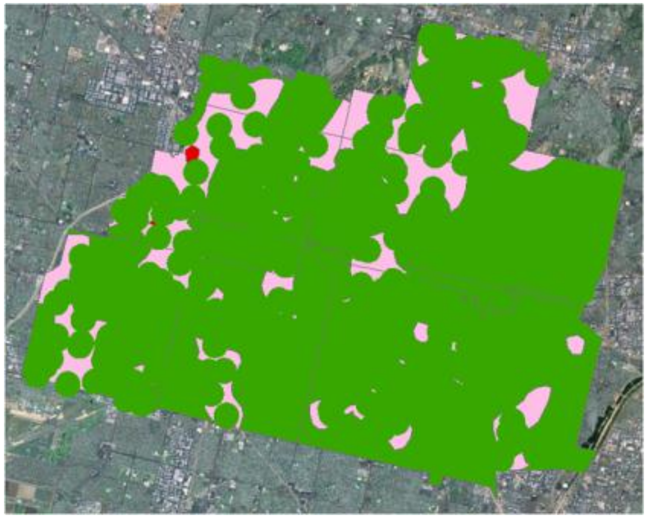
# Fiber for Backhaul

"Backhaul first / coverage next" approach

- Optimally select fiber access points as small cell locations (yellow dots) outside macro cell (blue dots) coverage to maximize total overage
- Look for other options to cover rest of the area; provided cost/business justified



Macro cell coverage



Macro + small cell coverage with optimally selected fiber access points as small cell locations

**Example: For 613 candidate small cells in a wire center boundary:**

- 50% coverage with 100 small cell sites
- 90% coverage with 200 small cell sites
- 99% coverage with 300 small cell sites

If say 200 sites are reachable by existing fiber (Fiber Access Points), then the remaining 10% coverage could be achieved by optimal new builds (fiber/microwave/ other means)

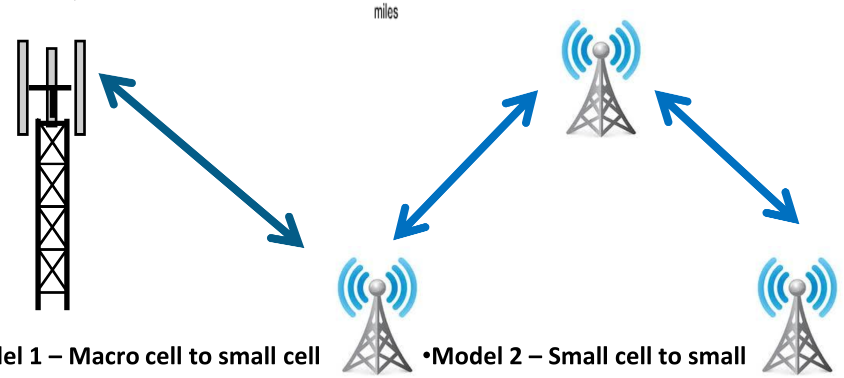
# Microwave for Backhaul


## Line of sight microwave

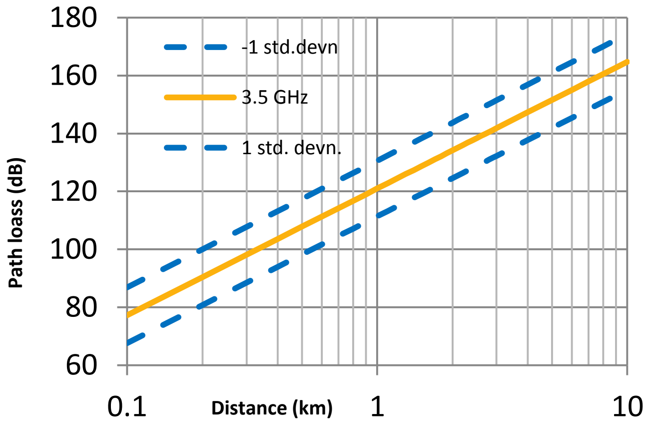
- Well defined models available taking into account:
  - Frequency of operation
  - Free space losses (obstruction of Fresnel zones)
  - Feeder losses, antenna size (gains)
  - Rain attenuation (predominant over 7 GHz)

## Non line of sight microwave

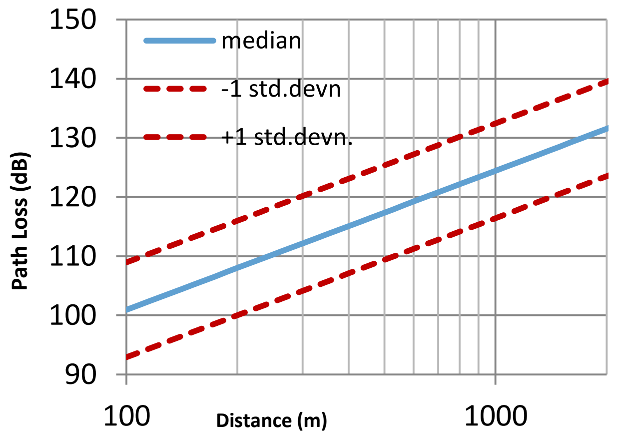
- Models developed for WiMax could re-used with some tweaks
- Two types of models recommended
- Applicable up to 6 GHz



- **Model 1 – Macro cell to small cell backhaul**
- **Model 2 – Small cell to small cell multi-hop backhaul**

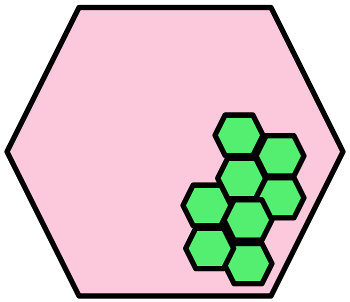



**Model 1 : 802.16d Type B model for 3.5 GHz**




**Model 2: WINNER II channel model for 3.5 GHz**

# Coexistence of Macro-cells and Small Cells



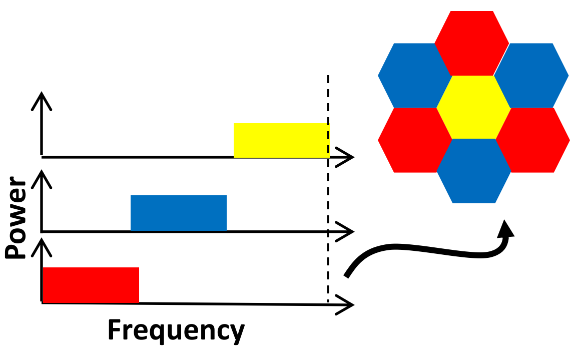
Interference management is a BIG problem

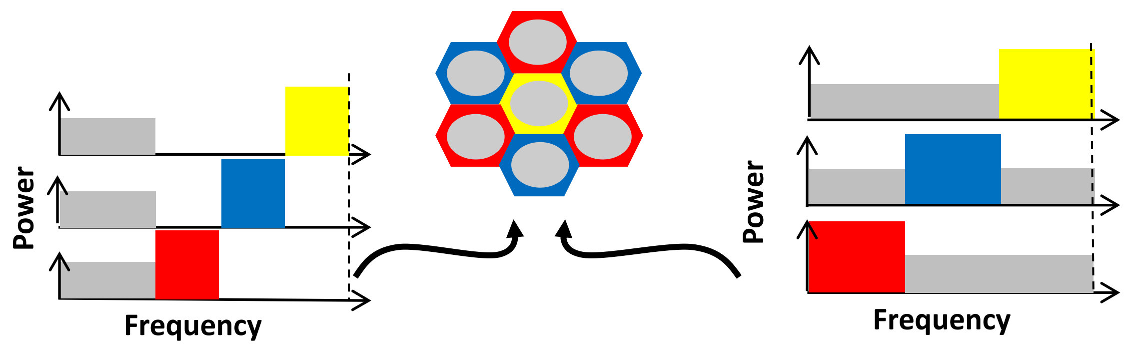
Two sources:

- Among overlapping small cells
- Between macro-cell and small cells within the macro's coverage

**Inter-Cell Interference Coordination (ICIC)**

- ICIC was introduced in 3GPP Release 8 to solve inter-cell intra-frequency interference.
- Divide each cell into cell center and cell edge and then allocate different subcarriers to subscribers at different power levels
- 3 frequency-reuse approaches:




**HFR: Hard Frequency Reuse**

**FFR: Fractional Frequency Reuse**

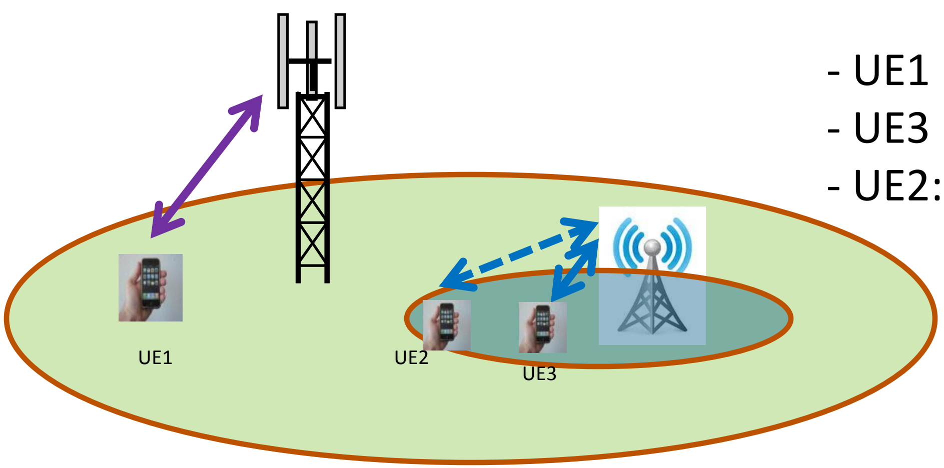
**SFR: Soft Frequency Re-use (preferable approach)**

# Interference Management Between Macro and Small Cells

- **ICIC** : Divide each cell into cell center and cell edge and then allocate different subcarriers to subscribers in different locations
  - Does not use the available bandwidth efficiently in macro-metro interference scenarios: metros would typically end up using only a part of the spectrum
  - Introduction of eICIC (3GPP Release 10)

- **eICIC:** Coordinate inter-cell interference on traffic and control channels in frequency, power, **and time** domains
  - Almost blank sub-frame (ABS) concept to coordinate inter-cell interference in the time domain
  - ABS only contains some necessary signals with low power

Macro sub-frames ....... | ABS | UE1 | UE1 | UE1 | ABS | UE1 | UE1 | UE1 | UE1 | ABS | .......




- UE1 : Always attached to macro
- UE3 : Always attached to small cell
- UE2: Scheduled to access small cell during ABS

# Carrier Aggregation (CA) in LTE advanced

**Available in R10+**

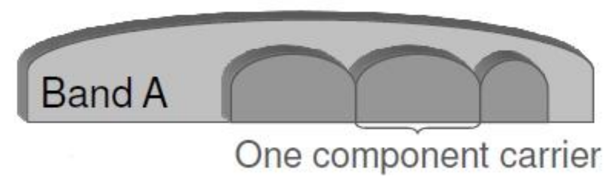
Two or more Component Carriers (CC) aggregated

- Support effectively wider transmission bandwidth in DL/UL between eNB and UE
- CCs of same or different widths can be aggregated
- Contiguous or otherwise

Can be inter-band based (Aggregated CCs may belong in different bands)

## Intra-band contiguous CA

•Applicable with SFR, where the available BW is split into 2 or more CCs




## Intra-band non-contiguous CA

•Aggregation of fragmented spectrum


## Inter-band non-contiguous CA

•Multiple CCs belonging to different bands are used e.g. 700 MHz and 1900 MHz are aggregated

•May require additional UE complexity (regarding the RF design)

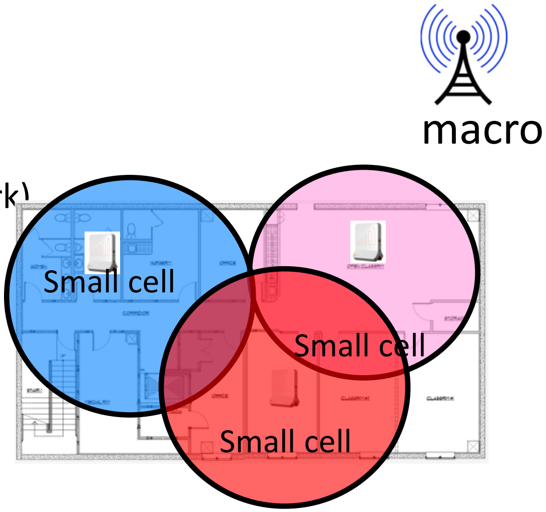
# AT&T Labs Research Initiatives – ICIC/eICIC/CA

## Analyze proposed schemes and devise new techniques

## Objectives

### Initial focus on indoor small cell deployment, with macro interference

- Derive usage guidelines for eICIC/ICIC/CA techniques
- Develop dynamic power control and frequency reuse algorithms (SON framework)
- Investigate feasibility of advanced CoMP techniques
- Explore opportunistic use of spectrum
  - Agile and Cognitive radio systems
- Closer interplay between WiFi and cellular
  - Hotspot 2.0
  - ANDSF



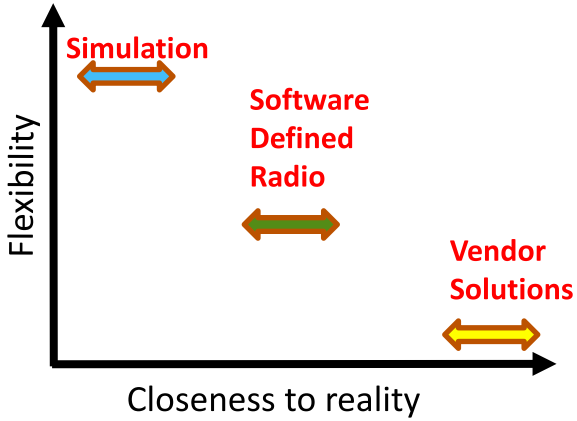

## Approaches

### Multi-pronged approach: explore different facets of problem by different approaches

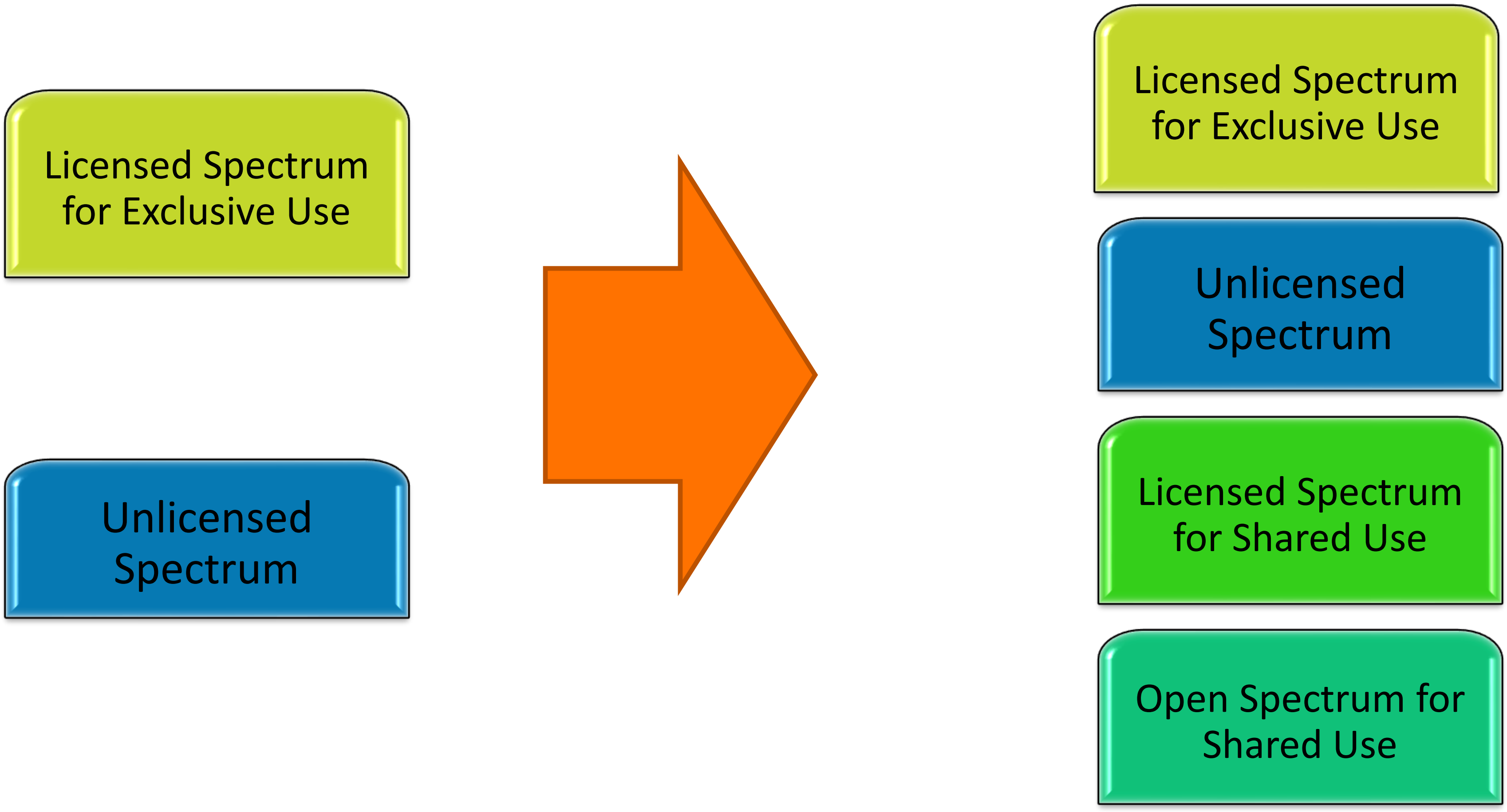
•Simulation: Test scalability and various environments

•Software-defined radio: Flexibility to implement new schemes and test *LTE-like* performance

•Vendor solutions: real LTE performance, limited options to implement new schemes



# Possible Regulatory Landscape Evolution




More options, but complex operating conditions to deal with.

# Technical Challenges Posed by Spectrum Landscape Evolution

- **Availability of spectrum**
  - How to make sure that a given band is available for use in a geographical area in a given time?

- **Sharing of spectrum**
  - What are the SLAs?
  - How to enforce SLAs?

- **Equipment to operate across wide bandwidth w/ multiple bands**
  - Base stations and user equipment

- **Network planning and performance**
  - Need highly automated network planning and performance management paradigms and tools

# Possible Sources of New Spectrum

- **TV White Space**
  - In the UHF band (specifically in the 470 MHz – 698 MHz range)
  - Unlicensed
  - Could be as big as 282 MHz
  - In many locales it could much less due to potential interference with TV stations

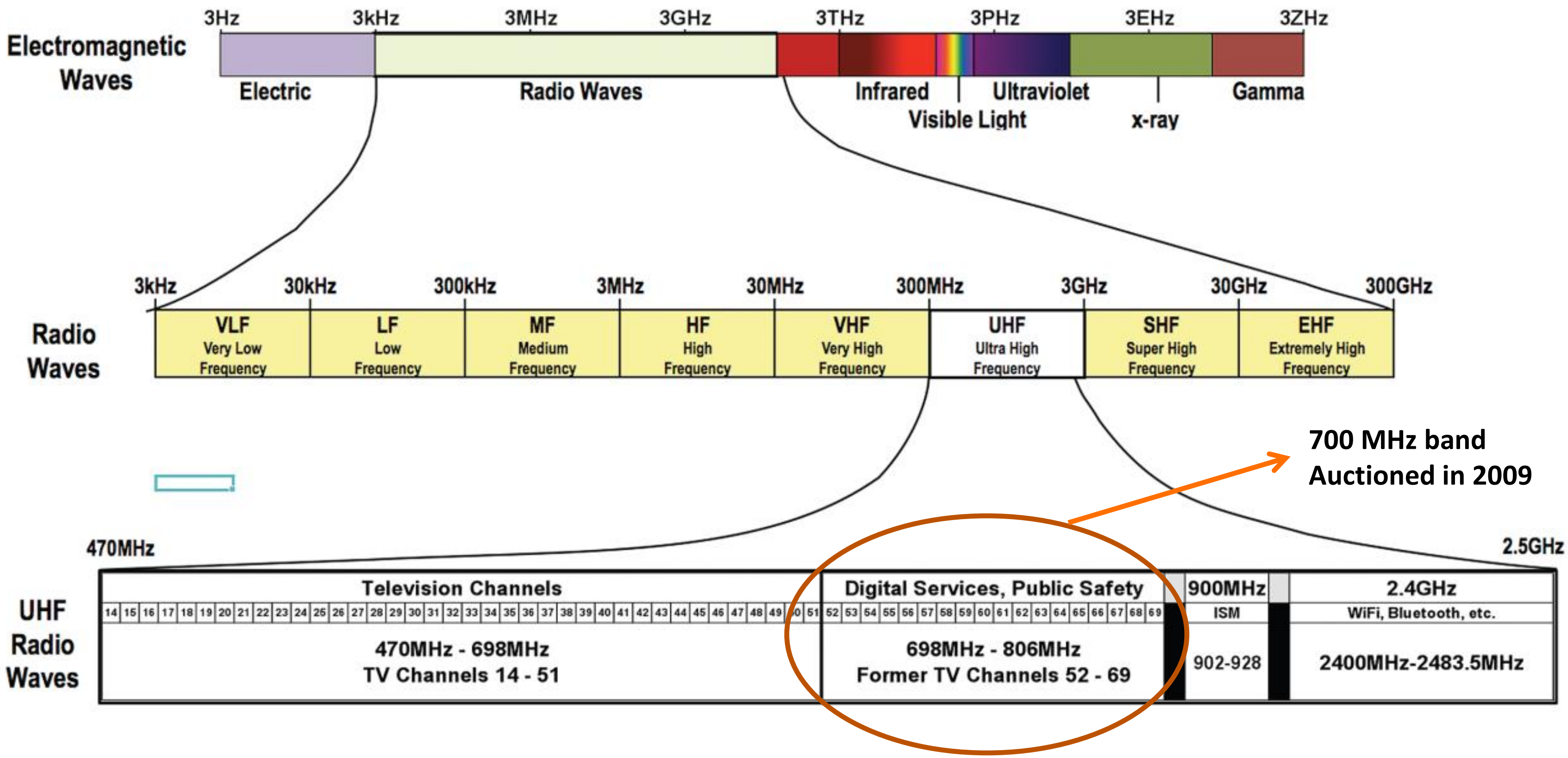
- **President's Council of Advisors on Science and Technology (PCAST) report to President Obama (July ,2012)**

- Recommends U.S. government to share underutilized spectrum to the maximum extent
- Requires to identify 1,000 MHz of federal spectrum in which to implement shared-use
- 2.65 GHz – 3.65 GHz band

- **Additional spectrum in bands recommended by CSMAC/NTIA**

- **Auctioning of TV broadcast bands** New

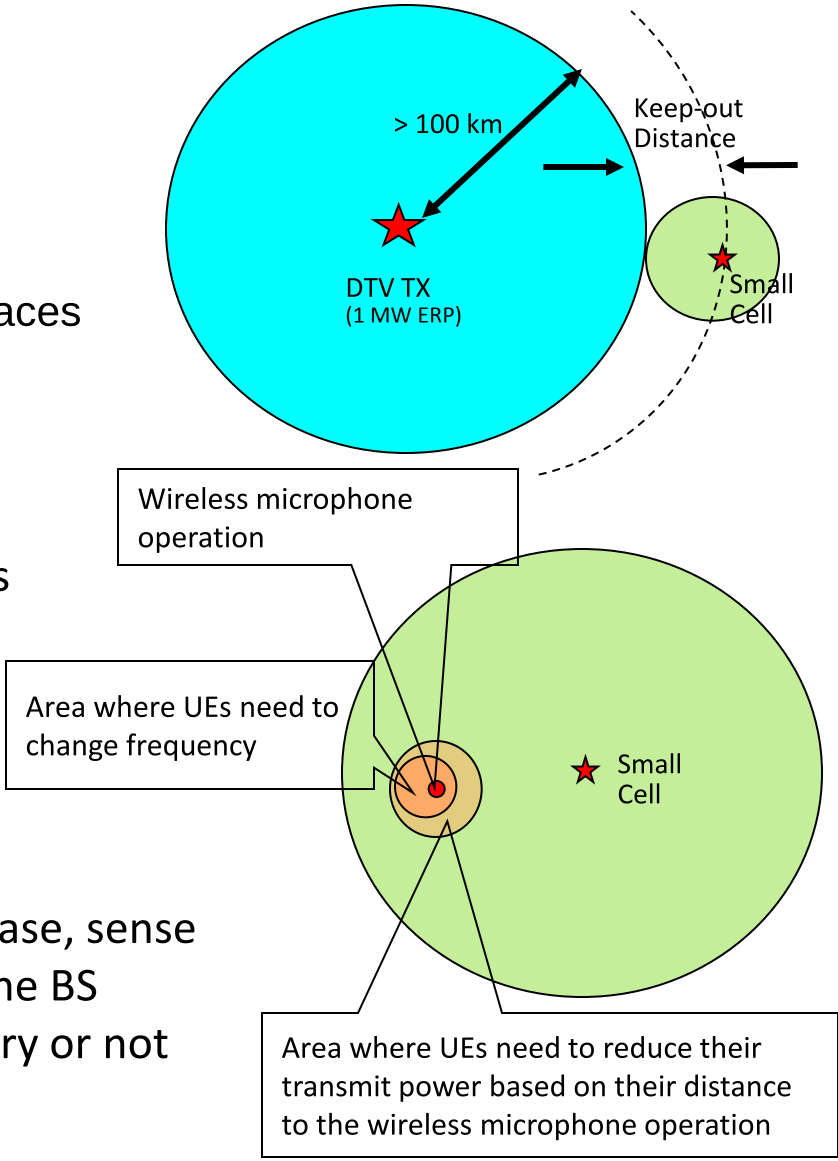
# TV White Space




- Each TV channel 6 MHz;  UHF band - channels 14 to  69  ( 55 channels)
- In a given geographical area, not all channels are use
- Robustness of Digital Television (DTV) signal allows DTV channels in adjacent channel spaces
- This helps to open up the **white spaces**

# Example Challenges in White Space Use

1. Protection of TV broadcasting systems
2. Protection of wireless microphones
3. Self-coexistence among systems using white spaces




**IEEE 802.22**

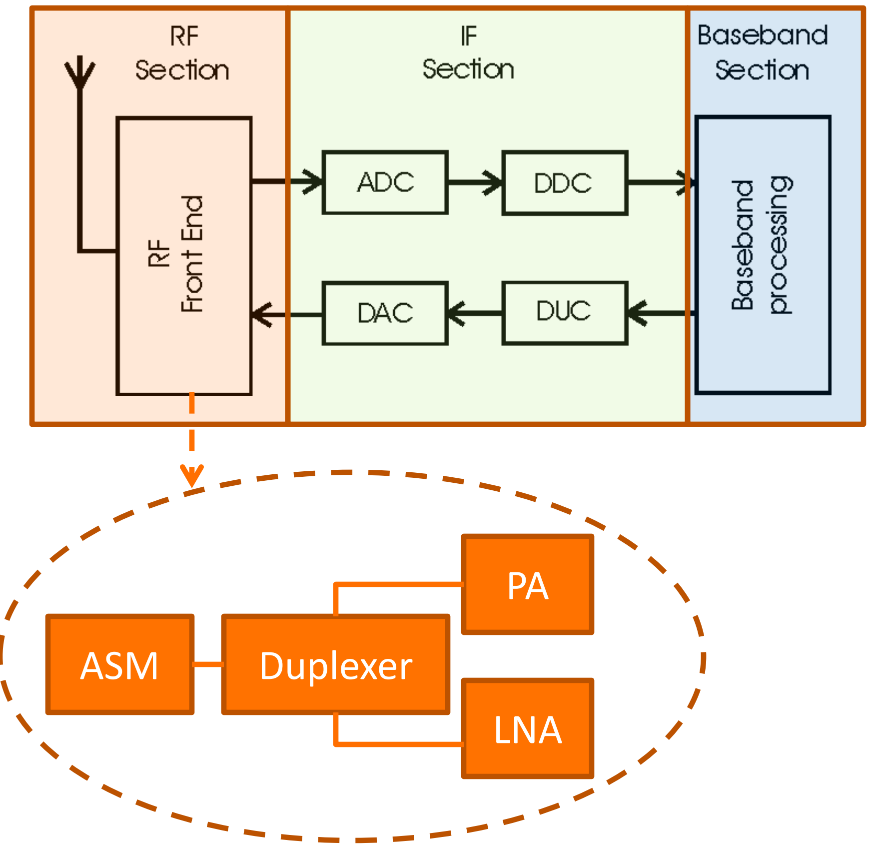
- Known as Super Wi-Fi – a standard for Wireless Regional Area Network (WRAN) using white spaces
- Aimed at using cognitive radio (CR) techniques to allow sharing white spaces

- WRAN Base Stations (BS) capable of performing a *distributed sensing*
- UEs must have ability to access a geo-spatial database, sense spectrum availability and send periodic reports to the BS
- BS evaluates whether a channel change is necessary or not

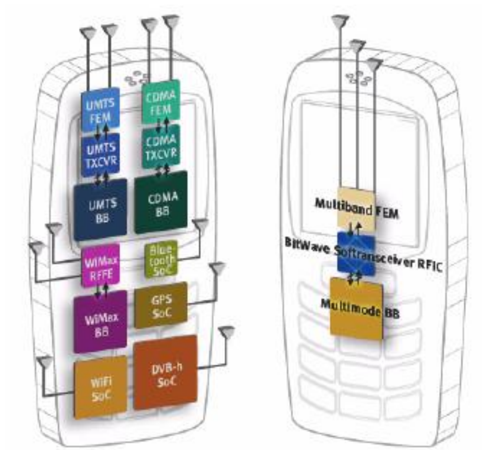
# Advanced Radio Designs

To make use of bandwidth that may be available in a wide range of spectrum (possibly from 400 MHz to 4GHz), conventional radios are not adequate

- Software defined radios and radios with tunable front end




- A full software defined radio should be programmable in all three sections (RF/IF/Baseband)
- Current state
  - Baseband, DDC, and DUC are programmable
  - ADC and DAC – more complex
  - Programmable RF section (front end module along with tunable antennas) still at its infancy



*Today's Multi-Mode Multi-band Handsets*

*A Softransceiver™ RFIC-Based Handset Solution*

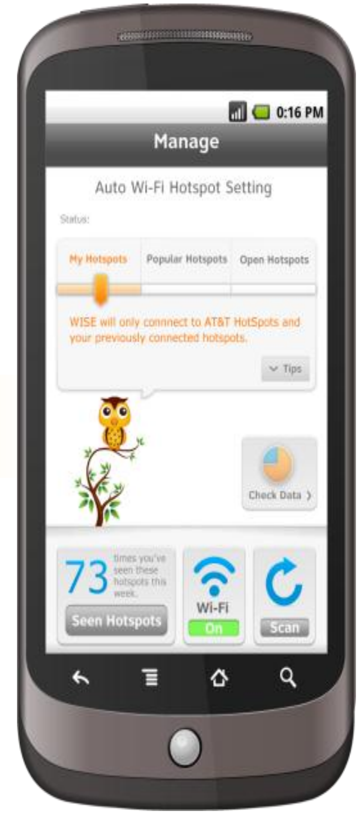
Source: Bitwave Semiconductors

ADC – Analog to Digital Convertor
DDC – Digital Down Convertor (demodulator)
DAC – Digital to Analog Convertor
DUC - Digital Up Convertor (modulator)

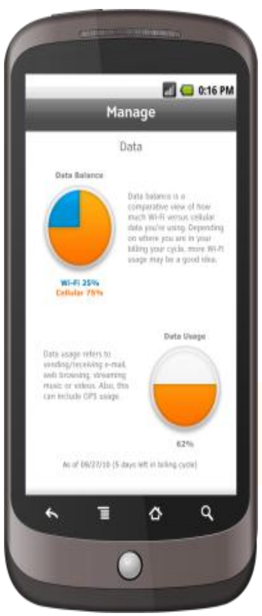
ASM – Antenna Switch Module
PA – Power Amplifier
LNA – Low Noise Amplifier

# AT&T Smart Wi-Fi - Intelligent Wi-Fi Experience

- Manage data use intelligently auto-connecting to Wi-Fi
- Preserve valuable cellular data usage for users
- Extend battery life over Wi-Fi always on
- Find and quantify new offload opportunities




## User Trial Results




- Average offload of 10 to 15 megabytes per day/per user
- 88% showed equal or improved battery performance
- 82% would recommend to friends/family
- 53% accessed new hotspots
- 76% increased Wi-Fi data usage
- Average Wi-Fi data usage increased more than 20% per user

## Helps Users Manage Data

- AT&T Smart Wi-Fi allows users to always know where they stand
- Wi-Fi and cellular data use tracked and displayed

# Unlicensed Spectrum Use:
# Bringing WiFi Closer to Cellular

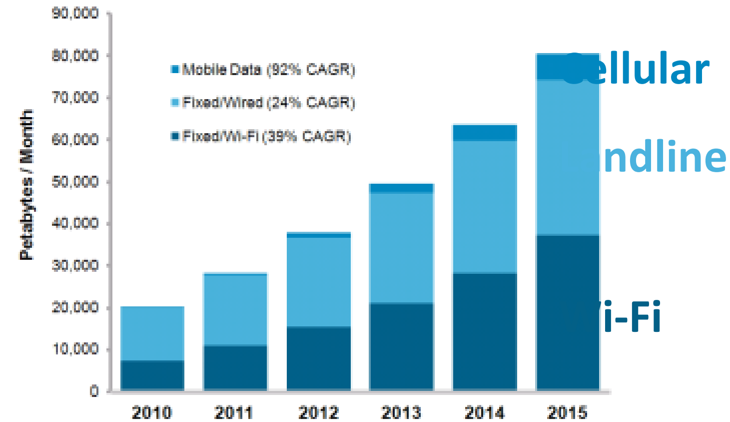
**Wi-Fi hotspots: increasing in number and usage**

**Efforts underway to make Wi-Fi closer to cellular:**

- Hotspot 2.0

- ANDSF

**Today, Wi-Fi is heavily used to off-load mobile data**



Source: CISCO

- Can we use Wi-Fi to fully complement cellular?
  - Main technical challenges stem from QoS
    - Registration
    - Security/authentication
    - Handoff
      - Critical for voice
    - Service quality management
    - Potential for interference
    - Usage accounting

# Concluding Remarks

- **Mobile data demand is exploding**
- **It is well recognized that current operator spectrum position is inadequate to meet the demand**
- **Shared spectrum approaches are new, and pose significant technical challenges to operators**
- **AT&T is working on innovative approaches to address industry needs**
  - Small cells: indoor and outdoor – maximum frequency re-use
  - New approaches to advanced radios and radio resource management
  - Next generation planning and performance management tools
  - Communication systems in Terahertz bands