A Survey on Femtocell:

[1] Femtocell Networks: A Survey

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[2] WiMAX Femtocells: A Perspective on Network Architecture, Capacity, and Coverage

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林咨銘

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Outline

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- Motivation
- Technical Aspects of Femtocells
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  - Synchronization
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Introduction

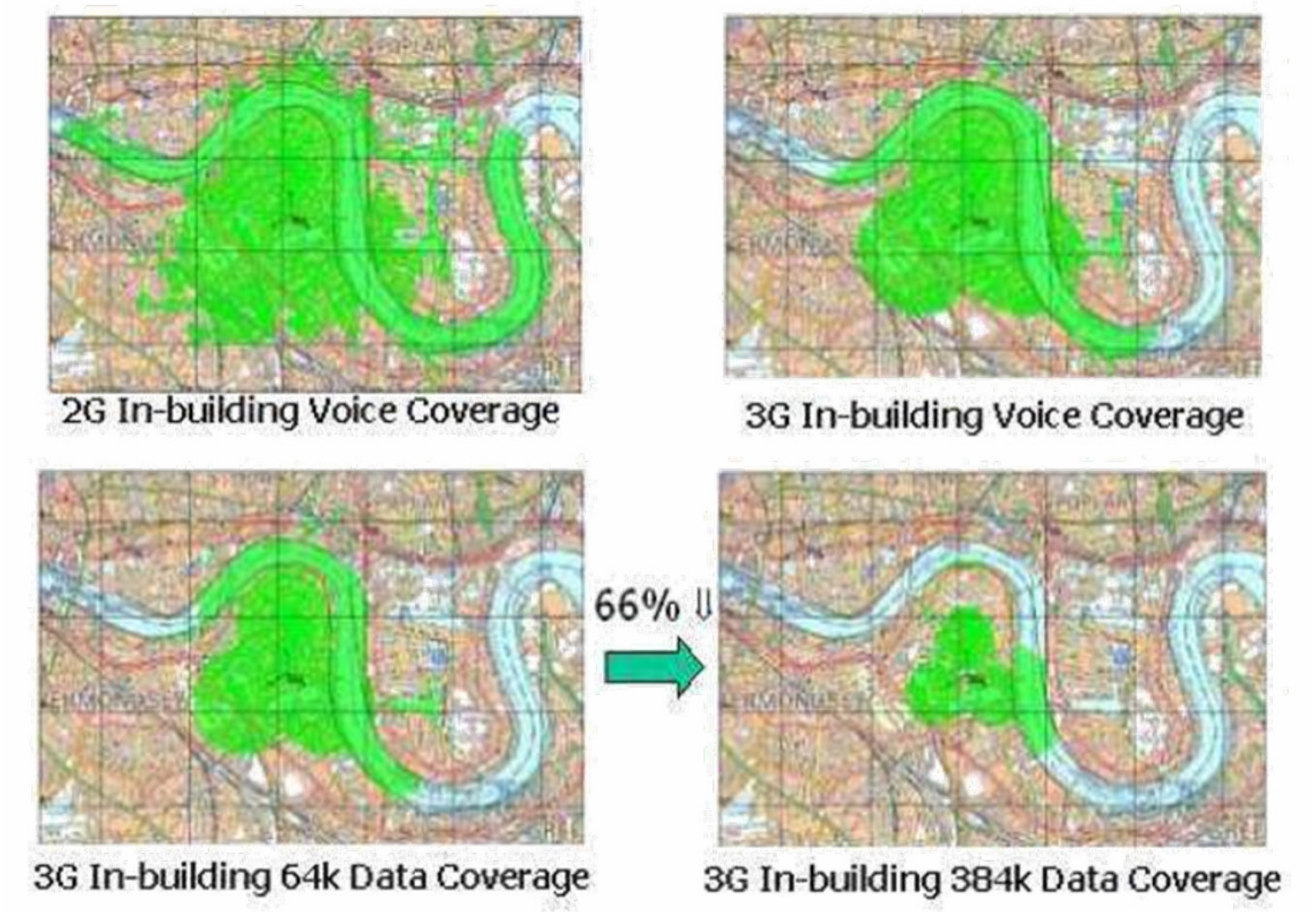
- The wireless capacity has doubled every 30 months since 1957
  - 25X improvement from wider spectrum
  - 5X improvement by dividing the spectrum into smaller slices
  - 5X improvement by designing better modulation schemes
  - 1600X gain transmit distance

- The main problem of current cellular network
  - The expensive deployment cost of network infrastructure
  - Low signal strength received from an outdoor BS inside a building

Motivation

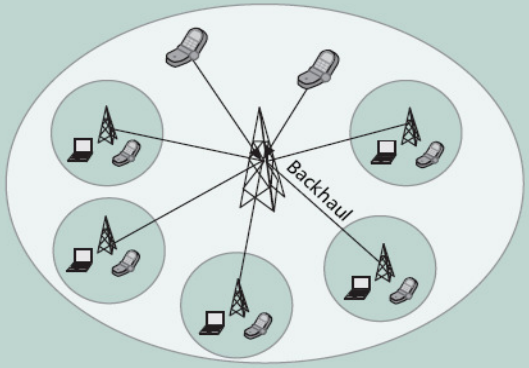
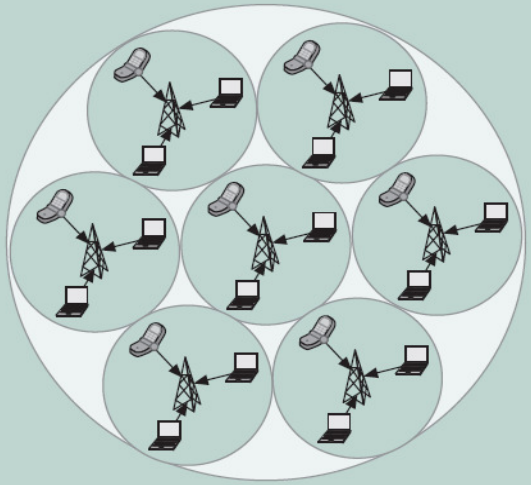
- Some studies on wireless usage show
  - More than 50% voice calls and more than 70% data traffic are originated indoor
- Win-Win strategy
  - Higher data rate and reliability for subscribers (User)
  - Reduced amount of traffic on expensive macrocell network (Operator)
    - Resource on truly mobile users can be focused

The Truth is…



Source : Pico Chip

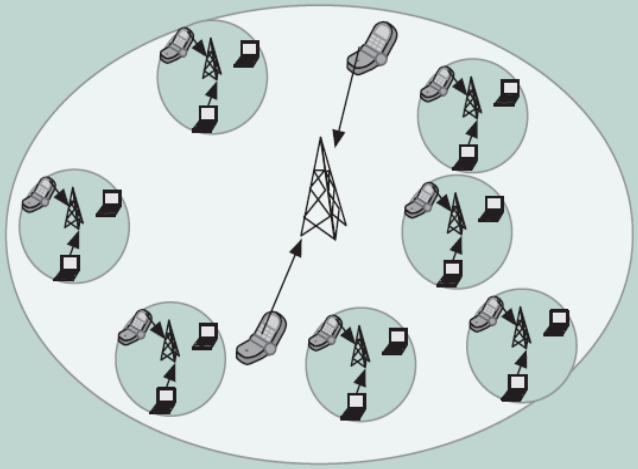
Some Solutions

Distributed antennas: Operator installed spatially separated antenna elements (AEs) connected to a macro BS via a dedicated fiber/microwave backhaul link. 	**Capital expenditure.** AE and backhaul installation. **Operating expenditure.** AE maintenance and backhaul connection.	**Benefits.** a) Better coverage since user talks to nearby AE; b) capacity gain by exploiting both macro- and micro-diversity (using multiple AEs per macrocell user). **Shortcomings.** a) Does not solve the indoor coverage problem; b) RF interference in the same bandwidth from nearby AEs will diminish capacity; c) backhaul deployment costs may be considerable.
Microcells: Operator installed cell towers, which improve coverage in urban areas with poor reception. 	**Capital expenditure.** Installing new cell towers. **Operating expenditure.** Electricity, site lease, and backhaul.	**Benefits.** a) System capacity gain from smaller cell size; b) complete operator control. **Shortcomings.** a) Installation and maintenance of cell towers is prohibitively expensive; b) does not completely solve indoor coverage problem.

Technical Aspects of Femtocells

- Femtocells
  - The smaller cell inside a building communicates with cellular network over a broadband connection
  - Femto-AP
    - A simplified low-power device that utilizes cellular technology with IP backhaul through a local broadband connection, e.g. DSL, cable modem, or RF backhaul channels

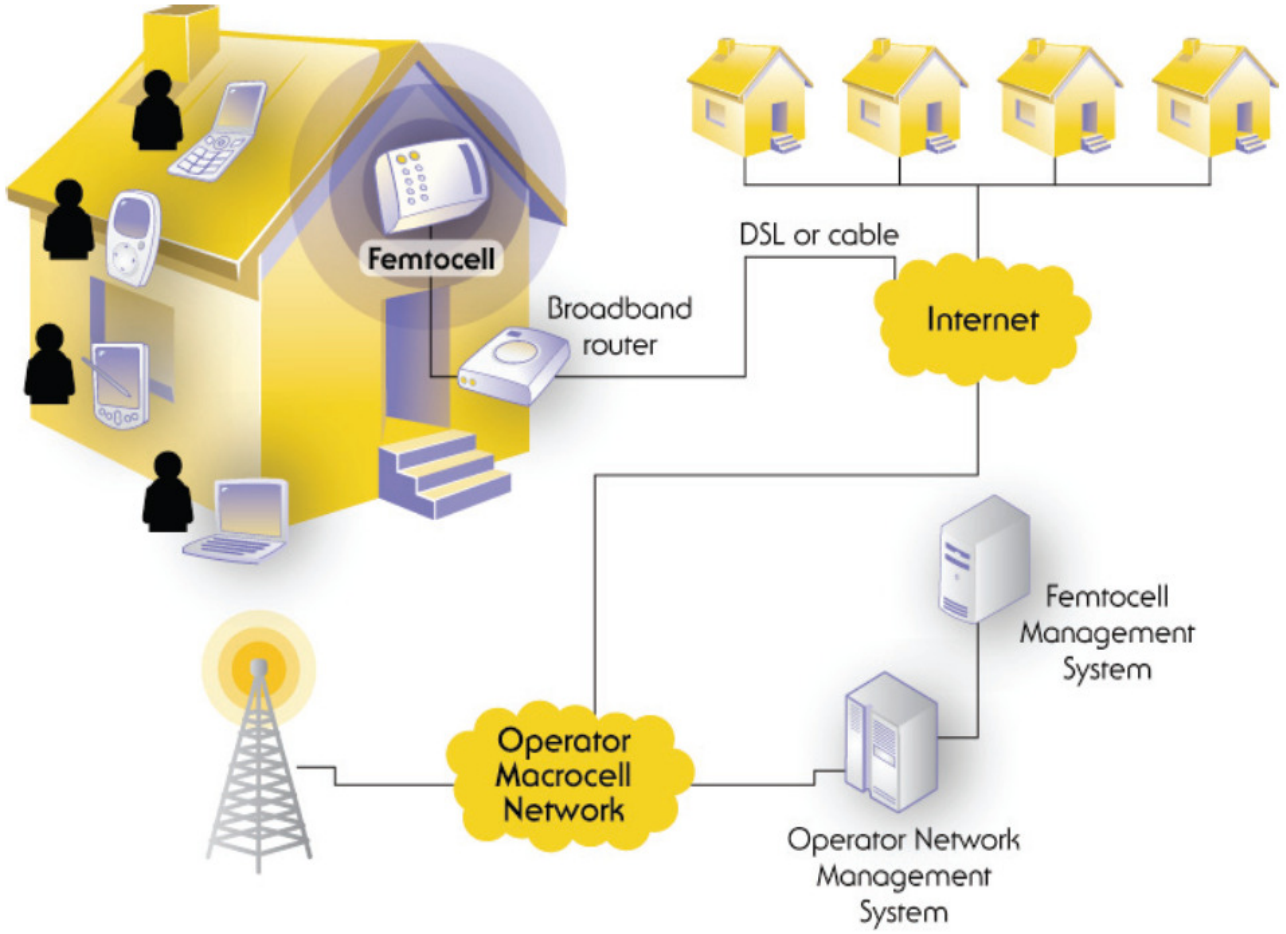
Femto Solution

Infrastructure	Expenses	Features
Femtocell: Consumer installed wireless data access point inside homes, which backhauls data through a broadband gateway (DSL/cable/Ethernet/WiMAX) over the Internet to the cellular operator network. 	**Capital expenditure.** Subsidized femtocell hardware. **Operating expenditure.** a) Providing a scalable architecture to transport data over IP; b) upgrading femtocells to newer standards.	**Benefits.** a) Lower cost, better coverage and prolonged handset battery life from shrinking cell-size; b) capacity gain from higher SINR and dedicated BS to home subscribers ; c) reduced subscriber churn **Shortcomings.** a) Interference from nearby macrocell and femtocell transmissions limits capacity; b) increased strain on backhaul from data traffic may affect throughput.

Benefits of Femtocells

- Better coverage and capacity
  - Due to short transmit-receive distance
    - Lower transmit power
    - Prolong handset life
    - Higher SINR
    - Higher spectral efficiency
- Improved macro reliability
  - BS can provide better reception for mobile users
    - Traffic originating indoors can be absorbed into femtocell networks over IP backbone
- Cost Benefit
  - $60,000/year/marcrocell vs. $200/year/femtocell
- Reduced subscriber turnover
  - Enhanced home coverage will reduce motivation for users to switch carriers

Typical Femto Deployment



Source : Femto Forum

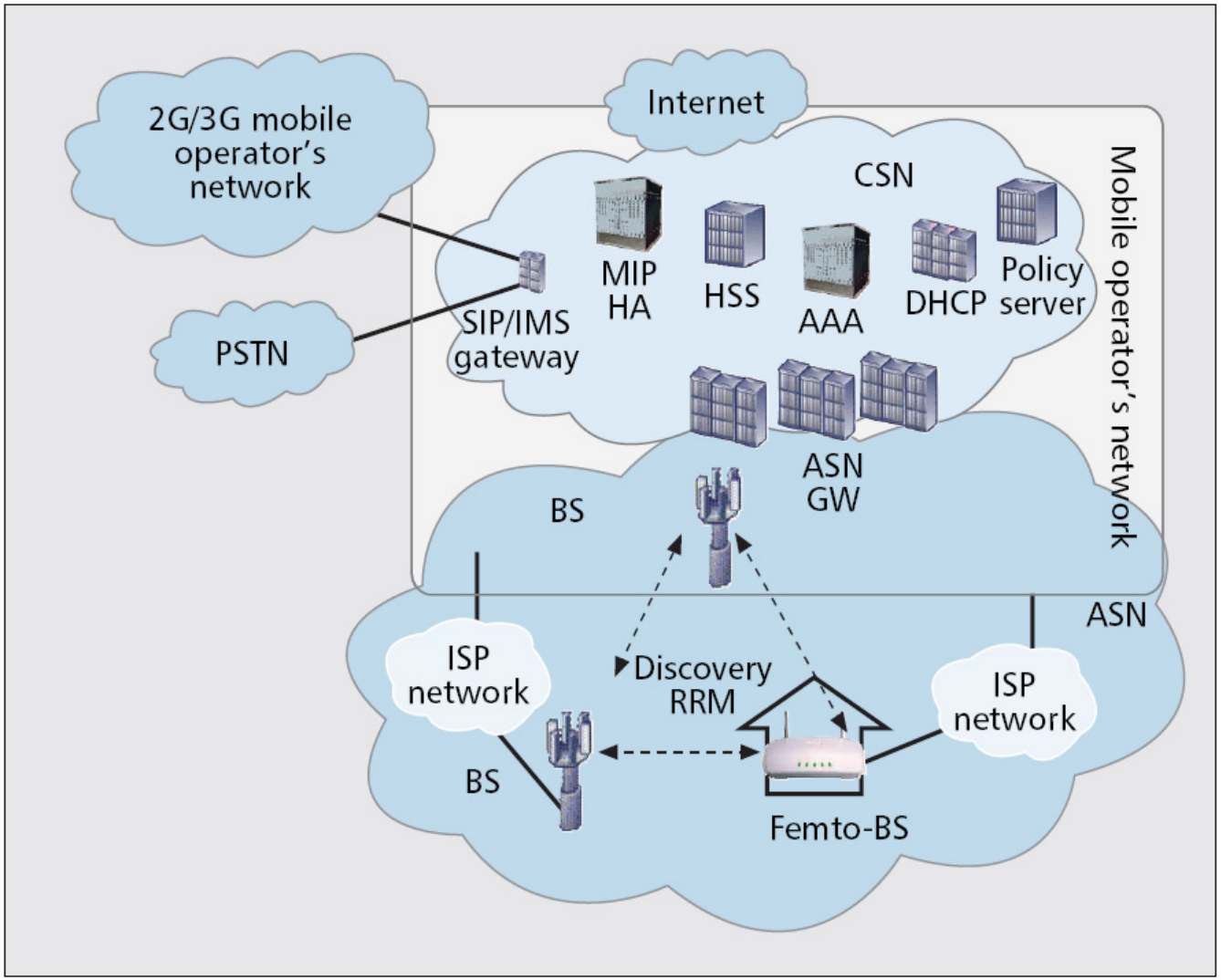
Benefits of Femtocells

- Capacity benefits of femtocell
  - Reduced distance between sender and receiver leads to higher signal strength
    [capacity improvement]
  - Lowered transmit power decrease the interference for neighboring cells
    [capacity improvement]
  - Femto-AP can devote a larger portion of resource for fewer users.
    [frequency efficiency]

Use Cases and Network Architecture

- The WiMAX network consists of :
  - Access Service Network (ASN)
    - An all-IP network structure is applied
    - Operator-owned macro/micro BSs and customer-owned Femto-APs are connected to local ISP networks
  - Connectivity Service Network (CSN)
    - Composing of services, such as an authentication, authorization, and accounting (AAA) server, Mobile IP, Home agent, and policy server.
  - ASN gateway
    - A interface between ASN and CSN
    - Marco/micro BSs and Femto-APs communicates with ASN gateway through packet-switched IP network.

Use Cases and Network Architecture



Coverage in Different Simulation Scenario

Indoor-to-Outdoor Interference

Co-channel Interference

Coverage (%)			Large cell scenario				Small cell scenario			
			Sparse deployment		Dense deployment		Sparse deployment		Dense deployment	
			Public	Private	Public	Private	Public	Private	Public	Private
FS transmit power	0 dBm	Indoor	99.7992	99.7992	98.3728	93.787	97.9310	93.7931	89.8050	70.0355
		Outdoor	75.4035	75.2498	72.9183	68.5603	71.3465	69.1297	67.8608	55.4464
	10 dBm	Indoor	100	100	98.8116	94.0828	99.0038	94.3295	91.3121	70.3901
		Outdoor	75.3267	73.1745	71.4397	57.4319	71.0181	64.1215	64.9468	33.4971
	20 dBm	Indoor	100	100	99.0385	94.1568	99.387	94.4061	91.1348	69.9468
		Outdoor	74.6349	68.6395	67.2374	37.7432	69.4581	51.6420	65.7658	13.5954
Coverage (%) without Femto-AP		Indoor	70.48		70.86		80.15		79.34	
		Outdoor	76.10		74.32		72.33		73.55	

Greater coverage than conventional network

Capacity in Different Simulation Scenario

Areal capacity gain *		Large cell scenario				Small cell scenario			
		Sparse deployment		Dense deployment		Sparse deployment		Dense deployment	
		Public	Private	Public	Private	Public	Private	Public	Private
FS transmit power	0 dBm	54.479	54.672	356.8325	364.1799	34.1512	34.3671	152.0866	151.5067
	10 dBm	57.764	59.1746	350.6903	384.0944	36.1507	37.5628	143.5709	153.5189
	20 dBm	57.4989	60.7799	319.2529	392.5468	34.9872	39.1827	134.7428	152.4803
System capacity without Femto-AP		25.921 Mb/s		27.377 Mb/s		27.621 Mb/s		27.551 Mb/s	

* Areal capacity gain = (system capacity with Femto-APs deployed)/(system capacity without Femto-APs)

- Femto-APs reuse the same bandwidth as macro-BS, so the available bandwidth per unit area increases
- Most users associated with Femto-AP experience little signal attenuation, which results in high SINR and SE for these users
  - Proportional to the number of Femto-AP per sector

Notes from Simulations

- Higher Femto-AP transmission power results in higher SINR and SE for indoor users

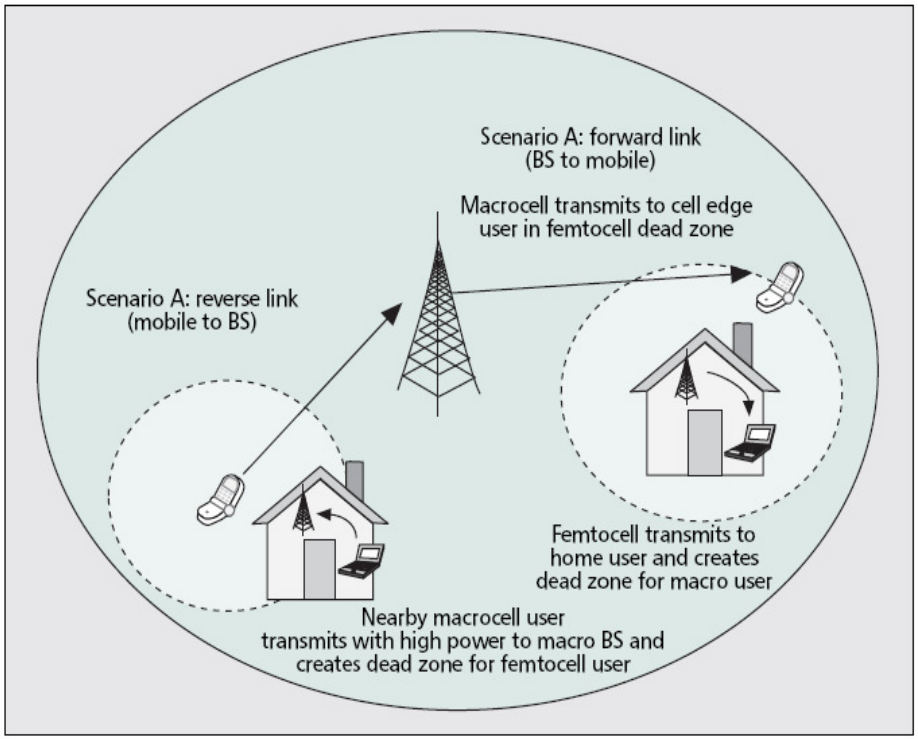
- When density of Femto-AP increases, the co-channel interference from neighboring Femto-AP get stronger
  - Reduce Spectral Efficiency (SE)

Technical Challenges

- Network Architecture
  - Typical RNC is in charge of radio resource management of about 100 BSs
    - Introducing Femto-APs increases the burden to RNCs
  - Because of flat all-IP network of WiMAX, more radio resource control needs to be implemented in Femto-APs for distributed management
  - New infrastructure support for seamless mobility management

Technical Challenges

- Interference Management
  - Power control is required in Femto-AP to avoid interference for outdoor users
    - Marcocell-to-Femtocell
    - Femtocell-to-Femtocell
    - Femtocell-to-Marcocell
  - Dead zone problem



-- For advanced interference mitigation strategies, good synchronization is essential

Technical Challenges

- Synchronization
  - The synchronization requirement for WiMAX is less stringent than 2G or 3G
    - 2ppm vs. 0.05ppm
    - However, 1 μs may be required for 4G OFDMA operation
  - Candidate calibration strategies
    - IEEE 1588
      - Self-adaptive timing recovery protocol
      - Master-Slave structure
      - 100ns timing accuracy
    - GPS
      - Popular and low cost solution for localization
      - Reception problem for indoor environment

Technical Challenges

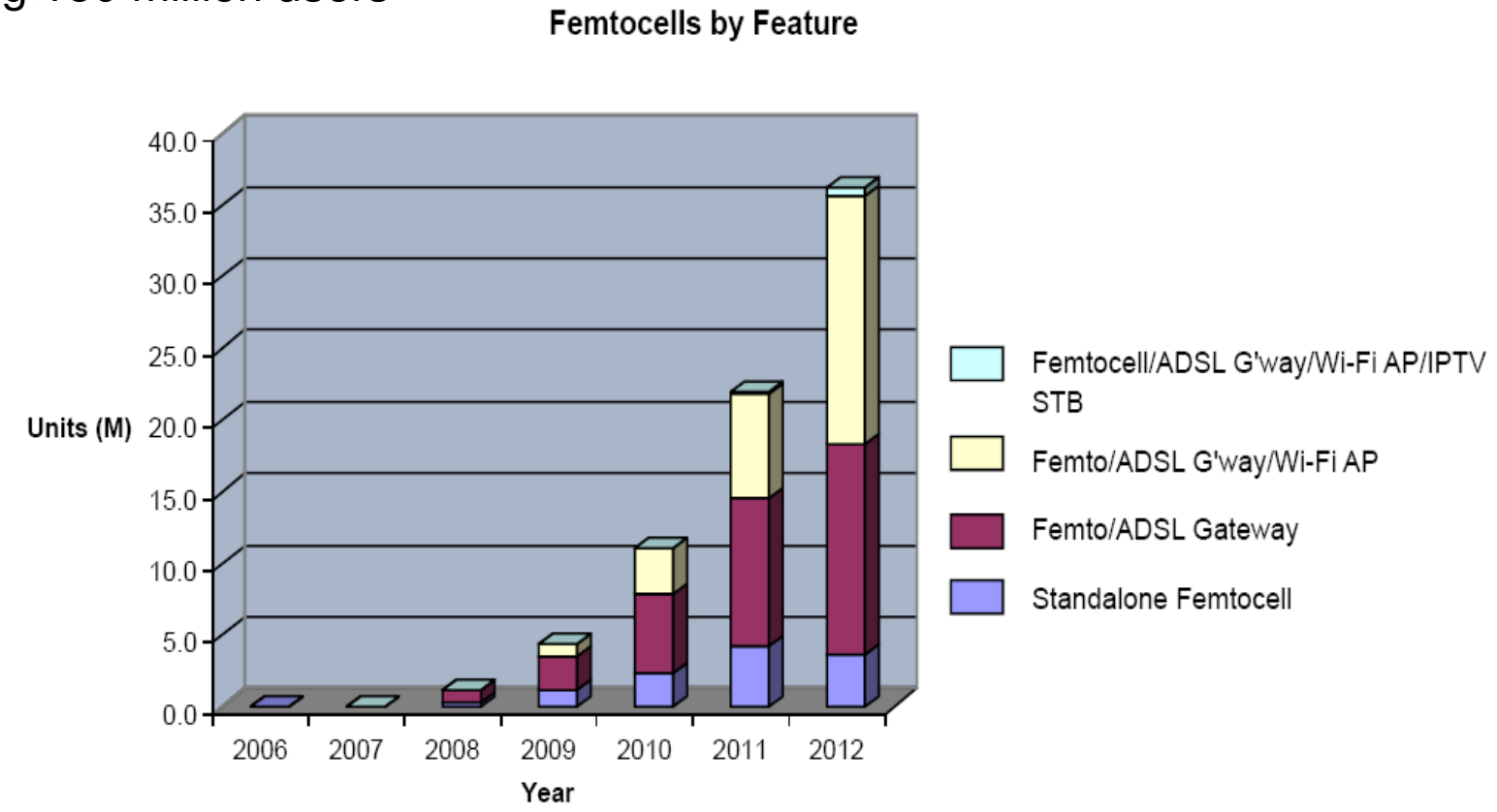
- Security and Performance
  - More sophisticated registration and authentication process and encryption of IP packets are necessary
    - Femto-APs utilize local ISP networks, which may be different from the operator's network
  - Collaboration and service level agreement between cellular and ISP operators are required
    - Cellular operator has no control over the channel and cannot prioritize voice packets from Femto-APs
    - For guarantying end-t-end QoS

Technical Challenges

- Self-Organization and autonomous operation
  - WiMAX networks requires a self-organization at both marco/micro BSs and Femto-APs because of the flat network architecture
    - E.g. handover are directly controlled by the BSs and Femto-APs
  - Femto-AP shall be a plug-and-play device that can integrate itself into the network without user intervention

Market Forecasts

By 2012, there will be 36 million shipments with an installed base of 70 million femtocell serving 150 million users



Source : Pico Chip

Conclusions

- Unsatisfactory coverage and the increasing number of high-data-rate application are two driving forces for femtocell development
- Femtocells have the potential to provide high-quality network access to indoor users at low cost
  - Improve coverage
  - Provide huge capacity gain
- From technical standpoint, some challenges shall be overcome
  - New network architecture
  - Interference mitigation
  - Synchronization
  - End-to-end QoS support
  - Seamless handover support