Mobility Management for Femtocells in LTE-Advanced: Key Aspects and Survey of Handover Decision Algorithms

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Small Cells

- *Key Challenge in Mobile Communications*
  - Smoothly integrate small-sized stations in the predominant macro-cellular layout
- Small Cells
  - Short-range, low-power and cost cellular access points
  - Support fewer users compared to macrocells
  - Embody the functionality of a regular base station
  - Operate in the mobile operator's licensed spectrum
  - Promising solution for supporting the plethora of emerging home/enterprise apps
  - Include pico, micro, metro cells: Operator-managed
  - Include femtocells: installed/managed by the users

Femtocells

- Special case of small cells [1]
- Installed/managed by the users
- Utilize existing broadband backhaul to reach the mobile operator's network, e.g., xDSL
- Support up to a few users, e.g. 4 users
- Low power operation, e.g. up to 20dBm
- Are subject to access control
  - Closed: Service to a closed group of subscribed users
  - Open : All users are allowed to utilize the femtocell
  - Hybrid: Preferential access to subscribed users
- Feature edge-based intelligence
  - Self-x capabilities, advanced radio resource, mobility and interference management

Femtocell Deployment Example
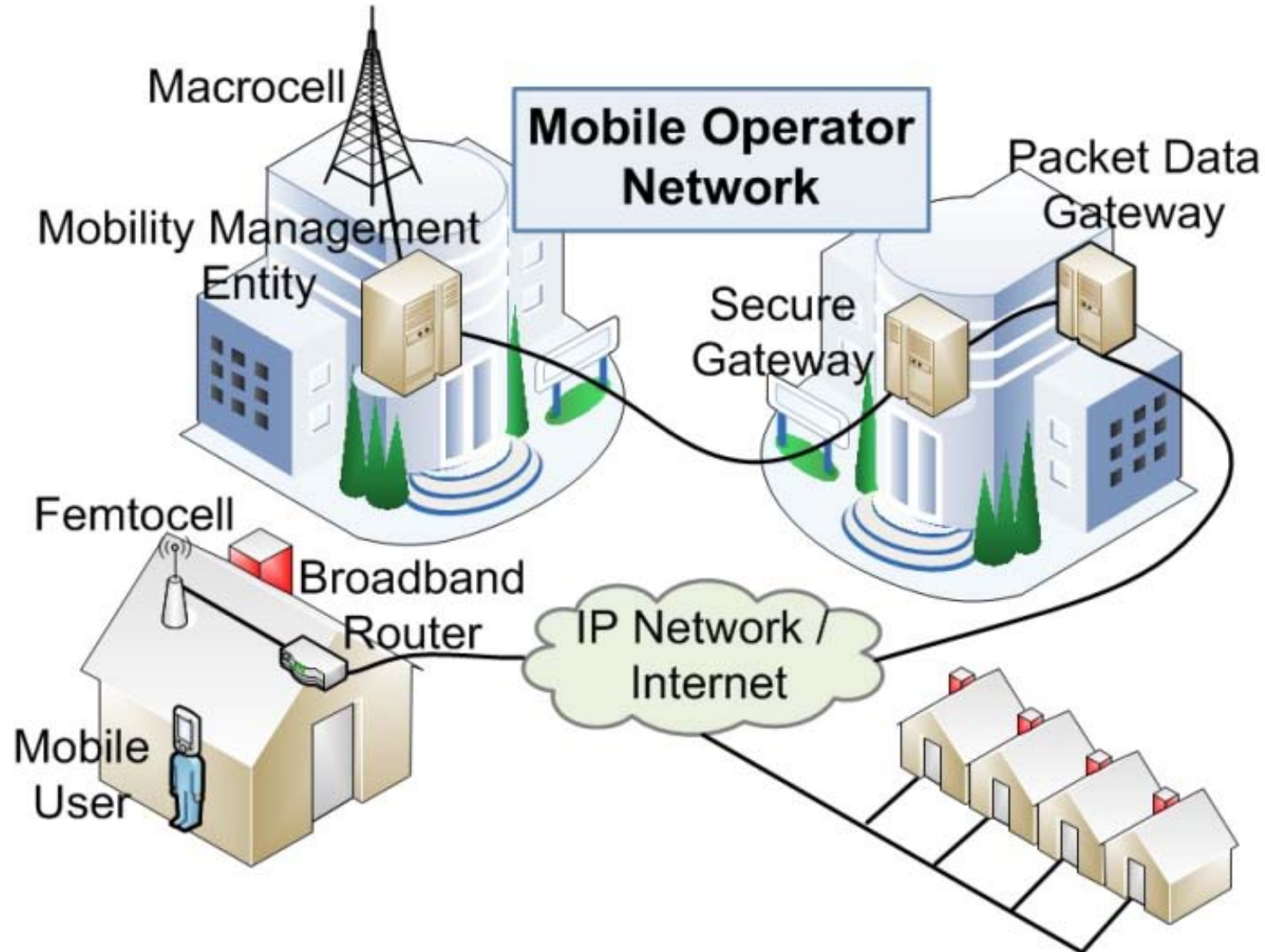
Femtocell Benefits

- Mobile Operator Perspective
  - Reduce the Capital and Operational Expenditure
    - Femtocells utilize the consumer's broadband backhaul
    - Femtocells are installed and managed by the end user
  - Improve indoor coverage and system capacity
  - Result in higher spatial frequency reuse
  - Lower power transmissions
  - Decongest nearby macrocells

- User Perspective
  - Improved indoor coverage
  - Enhanced system capacity – end throughput
  - Prolonged handset battery lifetime
  - Preferential charging
    - Utilize the consumer's broadband backhaul

Femtocell Open Issues

- Business Models / Access Methods [1][13]-[14]
- Radio Resource Management [15]-[17]
  - Resource Allocation and Power Control
- Energy Saving Management [18]-[22]
  - Network : Component and System Level ES
  - User side: Enhance the UE energy-efficiency
    - Discontinuous Reception (DRX) [30]-[32]
- Interference Management [2] [23]-[29]
- Self-organization, configuration and healing [1]
- Location Management [38]
- Mobility Management [33]-[61] [69]-[73]
- Performance Analysis [62]-[64] [41]-[43] [48]

LTE-Advanced

- Technological advancement of the Long Term Evolution System Rel. 8/9
- Meets and surpasses the requirements set by the International Telecommunication Union (ITU) for the IMT-Advanced system [3]-[4]
- Incorporates a plethora of technical improvements to the LTE system [5]-[9]
  - Carrier aggregation
  - Advanced multi-antenna techniques
  - Relaying
  - Enhanced support for heterogeneous deployments, including femtocells

Part I: Mobility Management for femtocells in LTE-A

- Overview of Part I
  - Motivation
  - Support of Femtocells in LTE-A
  - Discuss the key aspects and research challenges
    - Cell Identification
    - Access Control
    - Cell Search
    - Cell Selection / Reselection
    - Handover Decision
   - Handover Execution

Part I: Mobility Management for femtocells in LTE-A

- Motivation
  - MM for femtocells is challenging
    - **Denser network layout and short-cell radii**
      - Augment the negative impact of user mobility
      - Enlarge the number of candidate cells
      - Increase the HO probability even for low speed users
    - **Access control restrictions**
      - Degrades the SINR performance under certain interference scenarios, e.g., closed access
    - **Unplanned deployment pattern**
      - Introduces randomness and dictates autonomicity
    - **Low-power operation**
      - The signal is more vulnerable to non line of sight (NLOS) propagation conditions and fast variations of the radio environment

Part I: Mobility Management for femtocells in LTE-A

- Support of Femtocells in LTE-A
  - E-UTRA Network Architecture
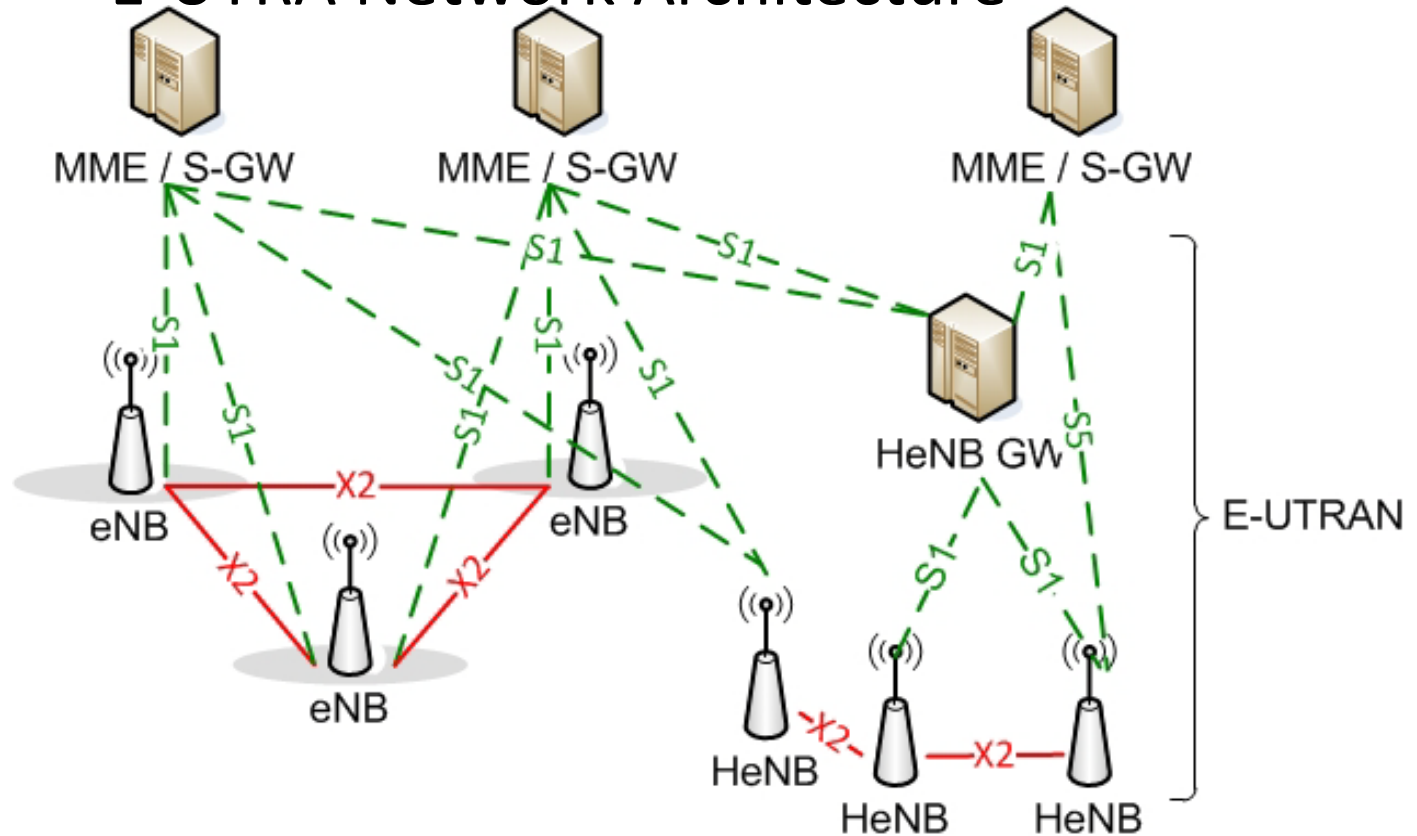
Part I: Mobility Management for femtocells in LTE-A

- ## Support of Femtocells in LTE-A
  - ### Evolved Packet Core (EPC)
    - **Mobility Management Entity (MME)**
      - Implements the functions of core network (CN) signaling for MM between 3GPP access networks, idle state mobility handling (e.g., paging), tracking area list management, roaming, bearer control, security and authentication
    - **Serving Gateway (S-GW)**
      - Hosts the functions of lawful interception, charging, accounting, packet routing and forwarding, and mobility anchoring for intra and inter-3GPP MM

Part I: Mobility Management for femtocells in LTE-A

- ## Support of Femtocells in LTE-A
  - ### Access Network
    - **Evolved Node B (eNB)**
      - User and control plane protocol terminations towards the UE
      - Supports the functions of radio resource management, admission control, scheduling and transmission of paging/broadcast messages, measurement configuration for mobility and scheduling, routing of user plane data towards the S-GW
    - **Home eNB**
      - Supports the same functionality as the eNB
    - **HeNB Gateway**
      - Concentrator for the control plane to support a large number of HeNBs in a scalable manner
      - Appears to the HeNBs as an MME and to the EPC as an eNB
      - Optional deployment

Part I: Mobility Management for femtocells in LTE-A

- Support of Femtocells in LTE-A
  - Interfaces
    - **X2 interface**
      - Allows direct connectivity between the eNBs
      - Allows direct connectivity between the HeNBs
        - » Different from LTE Rel. 8/9
      - Is not supported for interconnection between eNBs and HeNBs
      - X2-based handover between HeNBs is allowed only if no access control is required at the MME
    - **S1 interface**
      - Interconnects the eNBs and HeNBs to the EPC

Part I: Mobility Management for femtocells in LTE-A

- Support of Femtocells in LTE-A
  - Technical Specifications related to MM for femtocells

| Technical Specification	Title	Relation to MM support of femtocells
3GPP TS 36.211 V10.4.0	Physical Channels and Modulation [89]	Describes the procedures followed to generate and demodulate the Reference Signals for MM
3GPP TS 36.214 V10.1.0	Physical layer; Measurements [90]	Describes standard UE and E-UTRAN signal quality measurements used for MM
3GPP TS 36.300 V10.7.0	Overall description [84]	Describes the network architectural and procedural E-UTRAN enhancements to support femtocells. It also includes the MM procedures followed in the presence of HeNBs
3GPP TS 36.331 V10.5.0	Radio Resource Control (RRC); Protocol specification [91]	Describes the structure, the information elements and the procedures followed to broadcast the system information blocks (SIB)
3GPP TS 36.410 V10.2.0	S1 general aspects and principles [87]	Describes general aspects of the S1 interface and defines the S1 interface protocol functions
3GPP TS 36.413 V10.5.0	S1 Application Protocol (S1AP) [88]	Describes the S1 interface procedures used to support various LTE-A functions, including MM
3GPP TS 36.420 V10.2.0	X2 general aspects and principles [85]	Describes general aspects of the X2 interface and defines the X2 interface protocol functions
3GPP TS 36.423 V10.5.0	X2 application protocol (X2AP) [86]	Describes the X2 interface procedures used to support various LTE-A functions, including MM

Part I: Mobility Management for femtocells in LTE-A

- Cell Identification
  - *Involves all the mechanisms and identifiers used to distinguish femtocells from macrocells and/or other femtocells*
  - Cellular networks use a limited number of Physical Cell Identifiers (PCI) to distinguish the cells
    - Broadcasting unique cell identifiers asks for increased signaling and radio resource overhead
      - Should be transmitted in frequent and periodic basis to allow their systematic acquisition
      - Are typically scrambled within the broadcast channel
  - In the presence of femtocells
    - Denser PCI reuse : infeasible for the network nodes to uniquely identify the target cells
    - Random PCI selection : the random deployment hinders the centralized assignment of PCI values

Part I: Mobility Management for femtocells in LTE-A

- Cell Identification: PCI Confusion Problem
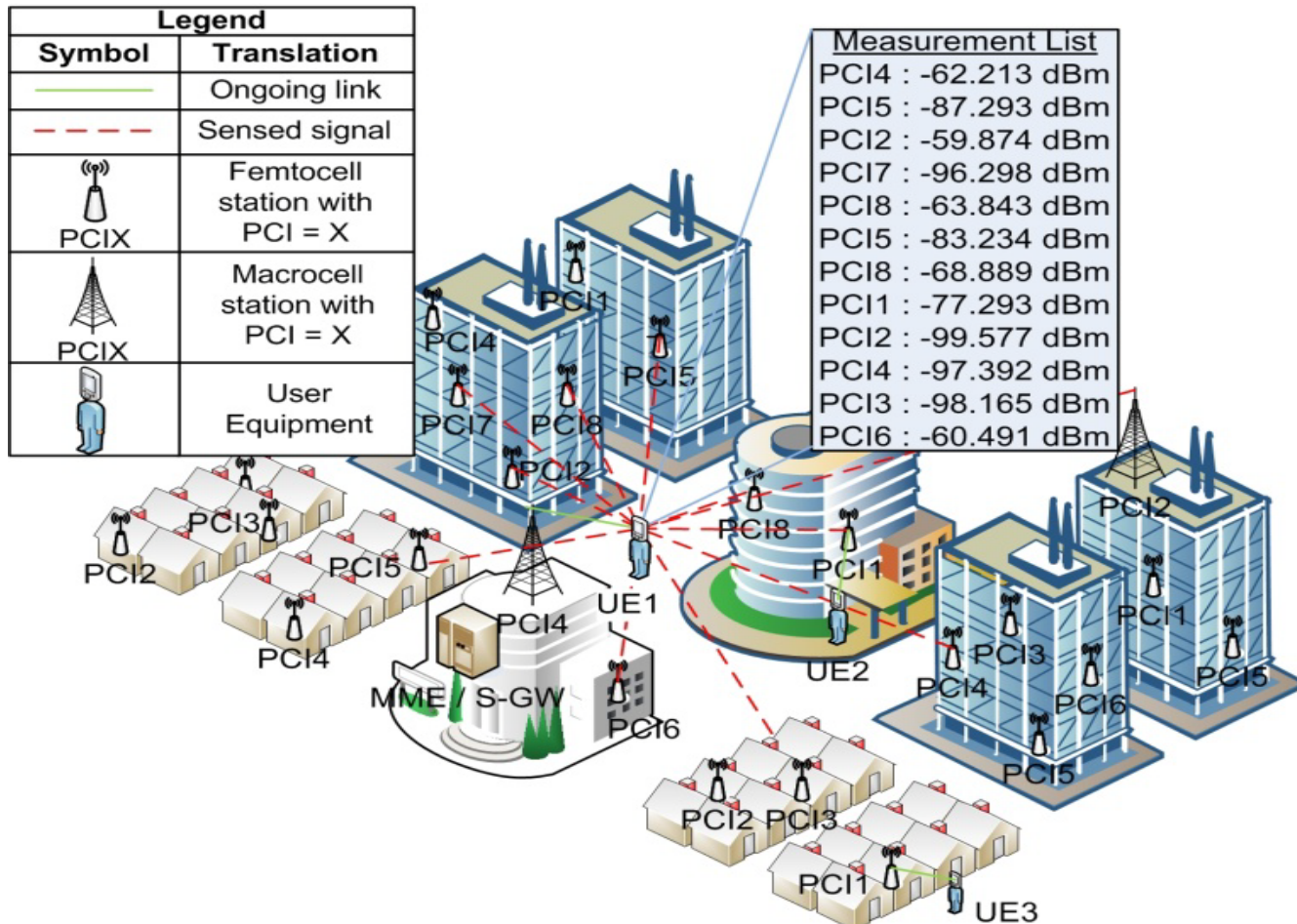
Part I: Mobility Management for femtocells in LTE-A

- Cell Identification
  - Research Challenges
    1. PCI Resolution: Use procedures that guarantee the unique identification of nearby cells
       - Hierarchical Cell Structuring: categorize the cells into different layers and introduce priorities
       - Separate PLMN ID for different cell tiers
       - Upper-layer approaches: acquire the unique cell global identifiers (CGI) transmitted in less frequently
         » Used as the main PCI resolution method in LTE-A
       - Carrier and PCI reservation for different cell tiers
         » Used as a complementary method in LTE-A
    2. PCI Selection: Minimize the negative impact of the PCI reuse by using distributed PCI selection algorithms
       - Current literature for PCI selection [92]-[98]
       - Need for distributed algorithms using cognition, cooperation, and context-awareness

Part I: Mobility Management for femtocells in LTE-A

- Cell Identification in LTE-A
  - LTE-A uses 504 unique PCIs
  - PCI Resolution
    - LTE-A resolves it by configuring the UEs to acquire the unique E-UTRAN CGI (ECGI) of the target cell
      - Introduces delay overhead (~80ms)
    - Provisions for PCI and carrier reservation
      - Need for utilizing this option to resolve the PCI confusion
  - PCI Selection
    - Centralized approach
      - The OAM system signals to the (H)eNB a specific PCI
    - Distributed approach
      - The OAM signals to the (H)eNB a list of PCI values
        » The (H)eNB chooses itself the PCI
      - LTE-A provides recommendations but does not specifies the distributed PCI selection algorithm

Part I: Mobility Management for femtocells in LTE-A

- Access control
  - *Involves the signaling, identifiers and procedures used to validate the membership status of a UE in a target femtocell*
  - Three access schemes
    - Closed: A specific group of users utilizes the femtocell
      - Exclusive utilization of the radio resources
      - SINR degradation due to cross-tier interference
    - Open: All users are allowed to utilize the femtocell
      - Minimizes cross-tier interference
      - Frequent service interruption, increased HO probability
    - Hybrid: Prioritized service to a specific group of users
      - Allows flexible resource utilization
      - Necessitates advanced admission control, handover decision and radio resource management algorithms

Part I: Mobility Management for femtocells in LTE-A

- Access control
  - Challenges in the presence of femtocells
    1. The UE should be aware of the closed groups it can access
    2. Femtocells should indicate the supported closed group
    3. A trusted network entity should validate the membership status of the mobile terminals

- Access control in LTE-A
  - UEs are part of Closed Subscriber Groups (CSG)
    - CSG and hybrid cells
  1. UE maintains a whitelist of CSGs
  2. HeNBs broadcast the CSG ID they support and the allowed type of access (CSG Indicator)
  3. Access control is always performed at the MME
     - Except if intra-CSG handover takes place

Part I: Mobility Management for femtocells in LTE-A

- Cell Search
  - *The procedure by which the UE acquires time and frequency synchronization with a nearby cell in order to identify it and measure its signal quality*
  - Based on
    - Signal measurements performed on pilot or reference signals broadcast by the cells in a predefined time - frequency basis
  - Triggered by
    - Events related to the status of the serving or neighbor cells, typically the RSS
  - Performed during
    - Idle DL or UL periods provided by DRX or packet scheduling (gap assisted measurements)
  - Configured by the network (typically)

Part I: Mobility Management for femtocells in LTE-A

- ## Cell Search
  - ### In the presence of femtocells
    - Dense yet unplanned deployment
      - Network inability to provide a comprehensive Neighbor Cell List (NCL)
        - » A limited number of NCL entries are allowed (e.g. 32)
    - Access control restrictions
      - NCL should be adapted on a per UE basis
  - ### Key performance trade-off:
    - Search and measure the signal quality of as much as possible nearby cells without consuming much of the energy saving opportunities (DRX gaps) or having frequent service interruption (resource gaps) or increasing the QoS maintenance overhead (gap scheduling)

Part I: Mobility Management for femtocells in LTE-A

- ## Cell Search
  - ### Research Challenges
    1. Develop UE-based autonomous cell search strategies
       - Use of context-awareness and cognition
    2. Construct a comprehensive NCL at the cells to assist the UEs
       - Shorten the cell search duration and enhance its accuracy
       - Use of context-aware and cooperative strategies
    3. Deploy femtocell-specific cell search triggering
       - Avoid frequent yet unnecessary measurements
       - Use of context-awareness, cognition and cell cooperation
    4. Deploy more sophisticated DRX and packet scheduling
       - Trade-off between the cell search accuracy/duration and the required QoS maintenance and energy overheads

Part I: Mobility Management for femtocells in LTE-A

- Cell Search in LTE-A
  - Is based on following the primary and secondary synchronization signals in the DL direction transmitted on specific subcarriers and slots [84]
  - UE can perform two basic measurements
    - Reference Signal Received Power (RSRP)
      - The RSS of a target cell (the RSS of other cells is excluded)
    - Reference Signal Received Quality (RSRQ)
      - RSRP to the RSS of all other cells in proximity
    - The RSRP and RSRQ are performed on specific RS
  - Cell search in LTE-A depends on the UE state
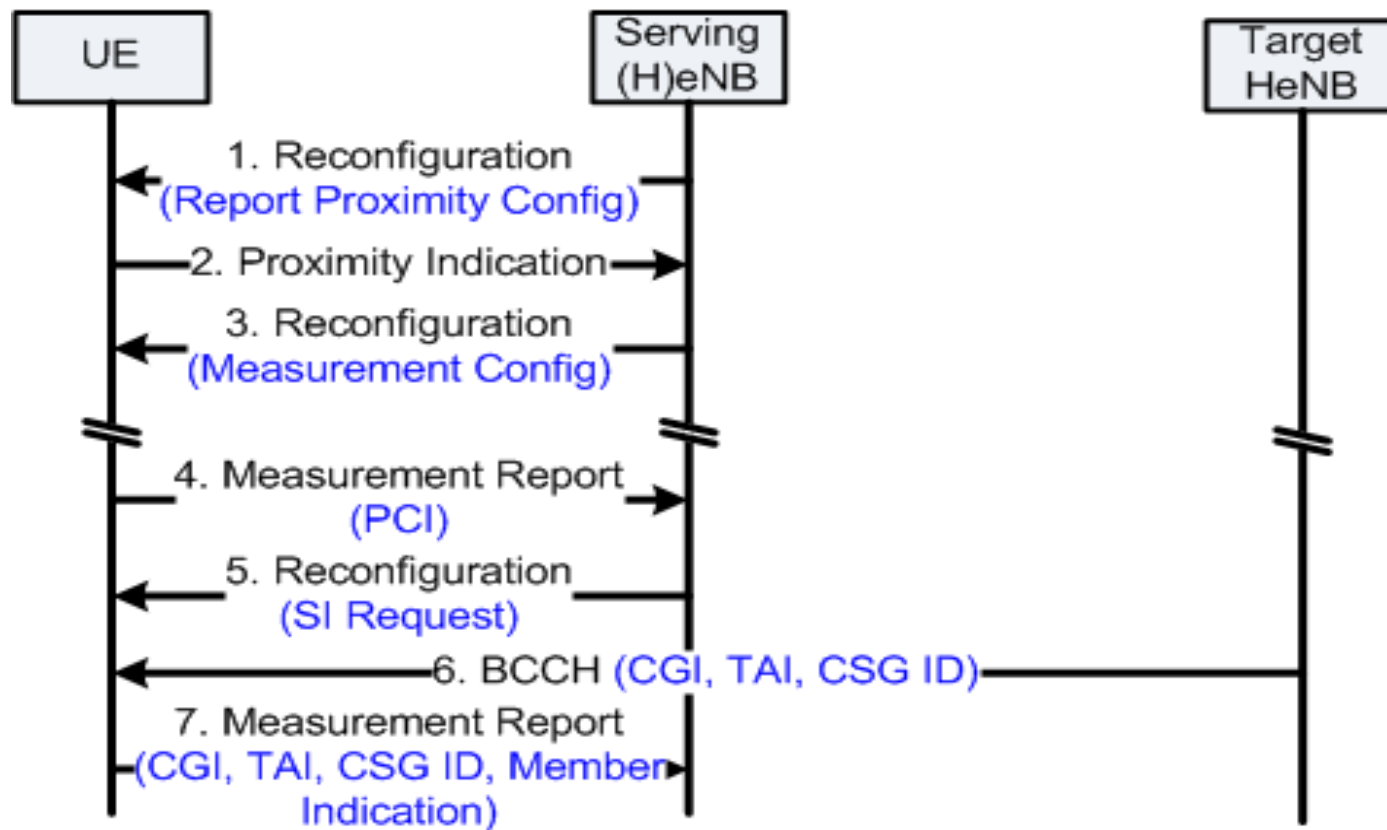   - Idle and connected state cell search

Part I: Mobility Management for femtocells in LTE-A

- ## Cell Search in LTE-A
  - ### Connected State (general)
    - Can be based on network configuration
    - Both event-triggered and period measurement reporting are enabled
    - The serving cell
      - Can provide black lists
      - Is not required to provide a NCL
      - Should at least indicate the carrier frequency for inter-frequency neighbor cells
  - ### In the presence of femtocells
    - The serving cell can use the feature of proximity estimation
      - Allows the UE to determine itself the presence of femtocells using autonomous cell search procedures

Part I: Mobility Management for femtocells in LTE-A

- Cell Search in LTE-A

  – Connected State

Part I: Mobility Management for femtocells in LTE-A

- ## Cell Search in LTE-A
  - ### Idle State (general)
    - Can be based on manual selection of CSG cells
    - Can be based on configuration provided by the network, e.g., NCL
    - Can be based on a UE autonomous search function
      - The UE determines itself when and where to search for cells
      - The cells can assist the UE by broadcasting a range of PCIs or carriers reserved for CSG use only

  - Both the UE autonomous search function (idle state) and the proximity estimation procedures are left up to the UE implementation

Part I: Mobility Management for femtocells in LTE-A

- Cell Selection / Reselection
  - *Cell Selection: the attachment procedure where the UE is idle and not camped on a cell*
    - UE switch-on phase or upon losing network coverage
    - Search all frequency bands, identify the cells operating in each carrier and follow a random access procedure to camp on the most suitable cell
  - *Cell Reselection: the inter-cell mobility procedure where the UE is idle and is already camped on a cell*
    - Measure the signal quality of nearby cells
    - Deploy cell ranking, or use frequency priorities provided by the network, or perform other optimization criteria
    - Can be assisted by the network with a NCL
  - Stored or cache information can be utilized to shorten the cell selection/reselection phases

Part I: Mobility Management for femtocells in LTE-A

- ## Cell Selection / Reselection
  - ### Research Challenges
    - #### Optimized formation of tracking areas (TA)
      - TAs are used to reduce the paging and cell reselection signaling overheads (cell grouping)
      - Even more challenging in the presence of femtocells
      - Performance trade-off: Using large TAs reduces the cell selection/reselection signaling and energy overheads at the UEs (less frequent TA update) but also increase the signaling, energy, and radio resource overhead at the network (more cells broadcast paging messages for a UE)
    - #### Deploy femtocell-specific cell selection/reselection
      - Increase the femtocell utilization / Offload macrocells
      - Anticipate with the required signaling and delay overhead for cell selection/reselection
      - Cope with the fast RSS variations and access control
      - Use stored or cache information

Part I: Mobility Management for femtocells in LTE-A

- Cell Selection / Reselection in LTE-A
  - Cell Selection
    - Search all frequency bands, identify the strongest cell for each carrier, and read the SI to identify the PLMN ID
    - Select the one that satisfies the cell selection criteria, belongs to the allowed PLMN, is not included in a black list, does not belong to a forbidden TA
  - Cell Reselection
    - Intra-frequency case: use of absolute frequency priorities
    - Inter-frequency case: Absolute priorities broadcast in SI
  - Cell selection/reselection for CSG cells
    - UE autonomous search function
    - Manual selection

Part I: Mobility Management for femtocells in LTE-A

- Cell Handover
  - *Consists of all the decision and signaling procedures required to seamlessly transfer the ongoing user connections from its serving to a neighbor cell*

- Handover Decision
  - *The decision part of the cell HO*
  - UE-assisted network-controlled in cellular networks
  - Used to offload highly congested cells or improve the signal quality at the UE
  - In the presence of femtocells
    - Frequent HO triggering (short cell radii, denser network layout, fast varying radio environment)
    - Uneven transmit power on the RS
    - Divergent interference levels among the cells
    - Opportunity to save energy and enhance the QoE

Part I: Mobility Management for femtocells in LTE-A

- Handover Decision
  - Research Challenges
    - HO decision triggering
      - Consider the use of other IMT-Advanced features instead
    - Account for the actual interference and RS transmit power status at the candidate cells (context-awareness)
    - Fully exploit the femtocell utilization opportunities while sustaining a low HO probability
    - Powerful tool for interference handling and energy saving management (macroscopic level)
    - Attain backwards compatibility and describe the required signaling procedures for context acquisition
    - Assess the performance of the proposed algorithms in terms of interference, energy-efficiency, and throughput
- Handover Decision in LTE-A is an open issue

Part I: Mobility Management for femtocells in LTE-A

- Handover Execution
  - *Consists of all the necessary signaling procedures for performing inter-cell mobility when the UE is in the connected state*
  - In the presence of femtocells
    - Requires increased signaling and delay overheads
      - Femtocells connect to the core network through the user's broadband backhaul
      - The signaling passes through additional network entities
      - Need to integrated femtocell-specific processes such as access control, PCI resolution, autonomous search
      - Existing femtocell-specific HO decision algorithms utilize an enriched set of parameters

Part I: Mobility Management for femtocells in LTE-A

- ## Handover Execution
  - ### Research Challenges
    - Optimize the wired and cellular backhaul under the viewpoint of femtocells
      - Use of femtocell gateways
    - Revisit and optimize existing HO execution signaling protocols
    - Smoothly integrate femtocell-specific processes into the standard HO execution procedure
    - Account for the additional HO execution signaling prior to HO decision making

Part I: Mobility Management for femtocells in LTE-A

- Handover Execution in LTE-A
  - HO execution scenarios

HO Scenario	Serving Cell	Target Cell	Access Control	HO Type	HO Execution Interface
1	eNB	eNB	Does not apply	Regular E-UTRAN	X2
2	HeNB	eNB	Does not apply	Outbound from HeNB	S1
3	(H)eNB	HeNB	Yes	Inbound to HeNB	S1
4	eNB	HeNB	No	Inbound to HeNB	S1
5	HeNB	HeNB	No	Inbound to HeNB	X2 / S1

  - Sc. 1 and 2 do not require procedural enhancements
  - Sc. 3,4,5 (inbound mobility to femtocells) necessitate the use of proximity estimation, the resolution of the PCI confusion problem and the employment of access control (scenario 3)

Part I: Mobility Management for femtocells in LTE-A

- Handover Execution in LTE-A

  – HO execution scenario 3 (most demanding)
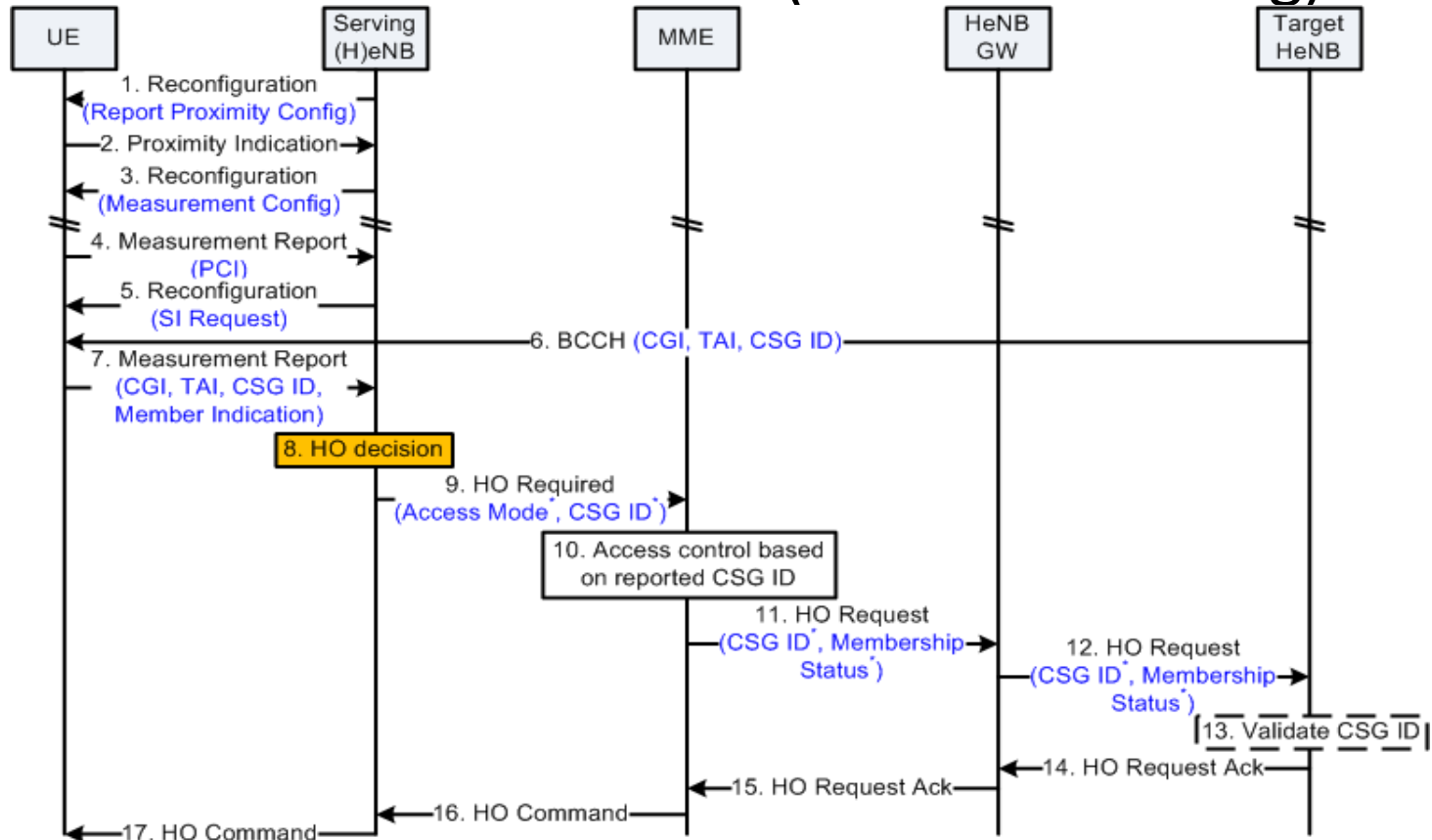
Part II: Handover Decision for femtocells in LTE-Advanced

- Overview of Part II
  - Handover Decision Criteria and Context
  - Classification of Handover Decision Algorithms
  - Survey of Handover Decision Algorithms
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  - Comparative Summary
  - Future Research Directions

Part II: Handover Decision for femtocells in LTE-Advanced

- Handover Decision Criteria and Context
  - *Received Signal Strength (RSS):*
    - Received power on the reference or pilot signals transmitted by a specific cell
    - The key decision parameter in cellular networks
    - A biased parameter in the presence of femtocells
      - Equals to the product of the (uneven) RS transmit power and the channel gain
    - Standard measurement capability in LTE-A (RSRP)
  - *Received interference power (RIP)*
    - Cell RIP: the total received power from (non-accossiated) users in proximity
    - UE RSSI: the total received power from cells in proximity
      - Received Signal Strength Indicator (RSSI)
    - Standard measurement capability in LTE-A
    - Acquiring the cell RIP increases signaling

Part II: Handover Decision for femtocells in LTE-Advanced

- Handover Decision Criteria and Context
  - *Received Signal Quality (RSQ)*
    - The ratio of the RSS from a target cell to the total RIP at the UE (signal quality based on the RS)
    - Standard measurement capability in LTE-A (RSRQ)
  - *UE speed*
    - Widely used to enhance inbound mobility to femtocells and reduce unnecessary HOs for medium to high speed users
    - Necessitates increased monetary, energy consumption or network signaling
  - *Energy-efficiency*
    - Critical parameter for IMT-Advanced mobile devices
      - Multifarious user applications and radio capabilities
    - Translated to the UE battery power [54], the mean UE transmit power [55], and the UE power consumption [60]

Part II: Handover Decision for femtocells in LTE-Advanced

- Handover Decision Criteria and Context
  - *Path loss*
    - Includes the impact of various signal attenuation factors caused by the wireless medium and the ambient radio environment, e.g., propagation, absorption and diffraction losses
    - Unbiased parameter in the presence of femtocells
    - Difficult to accurately estimate
  - *RS transmit power*
    - Cell transmit power on the RS
    - Can be used to estimate the actual path loss
    - Standard measurement capability in LTE-A
  - *Traffic type*
    - Existing classifications include real or non-real time traffic [47], [49], [53], [54], and voice or data traffic [52]

Part II: Handover Decision for femtocells in LTE-Advanced

- Handover Decision Criteria and Context
  - *Available bandwidth*
    - Measures the resource availability in the target cell
    - Used to perform preliminary admission control
    - Refers to the cell load, capacity, number of connected UEs
  - *UE residence time within the cell*
    - The duration that a tagged UE is expected to remain within the coverage of a cell
    - Used to minimize the number of unnecessary HOs
    - Difficult to estimate
  - *UE membership status*
    - Unique femtocell feature
    - Used to minimize the HO failure probability due to access control

Part II: Handover Decision for femtocells in LTE-Advanced

- Classification of Handover Decision Algorithms
  - Noteworthy amount of HO algorithms for femtocells [41]-[60]
  - Classification based on the primary HO decision parameter under use
    - Allows for simple comparison and useful insights
    - Most of the existing algorithms utilize parameters that span over the identified classes

  - HO decision classes
    - *Received signal strength based algorithms*
    - *Speed based algorithms*
    - *Cost-function based algorithms*
    - *Interference-aware algorithms*
    - *Energy-efficient algorithms*

Part II: Handover Decision for femtocells in LTE-Advanced

- Classification of Handover Decision Algorithms
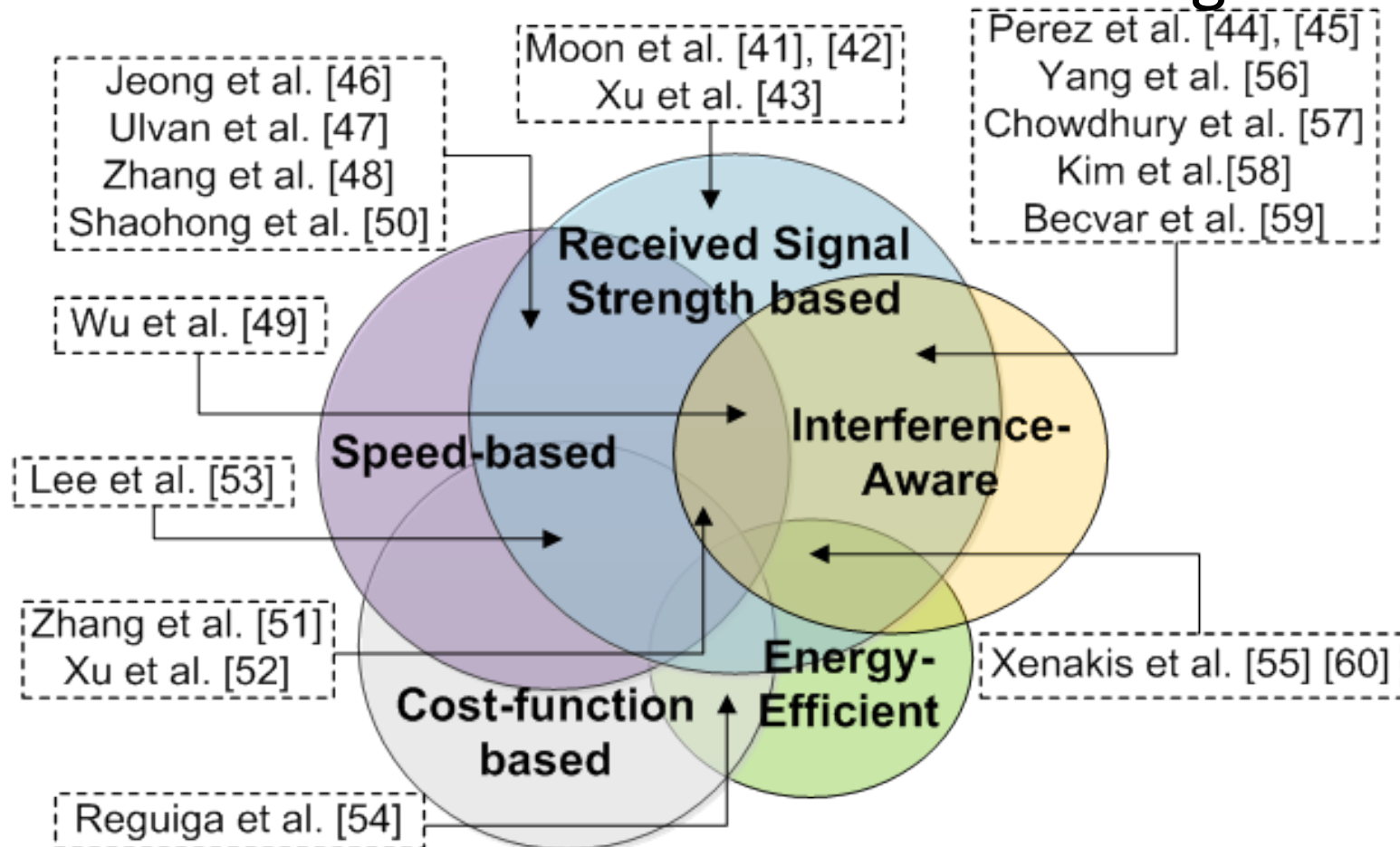
Part II: Handover Decision for femtocells in LTE-Advanced

- Classification of Handover Decision Algorithms
  - *Received signal strength based algorithms* [41]-[46]
    - The decision outcome is primarily based on the RSS
    - Existing approaches for using the RSS
      - Relative RSS comparison of the serving and the target cells, either directly or with hysteresis margin
      - Absolute RSS comparison of the serving or the target cell with absolute thresholds
      - Combination of these approaches
  - *Speed based algorithms* [47]-[50]
    - The decision outcome is primarily based on the UE speed
    - The HO decision is primarily taken by comparing the UE speed to absolute thresholds
    - Speed based algorithms account for other criteria
      - RSS, traffic type, cell load

Part II: Handover Decision for femtocells in LTE-Advanced

- Classification of Handover Decision Algorithms
  - *Cost-function based algorithms [51]-[54]*
    - Integrate a wide range of parameters within a single cost-function
      - Multi-parameter function or weighted sum
    - A HO is initiated when the cost-function outcome of a nearby cell exceeds over the one of the serving cell
  - *Interference-aware algorithms* [55]-[59]
    - Account for the interference at the UEs or the cells
      - Main parameters include the cell RIP and the RSQ
    - RSQ-based interference-aware algorithms
      - Similar approach with the RSS comparison
    - Cell RIP-based interference-aware algorithms
      - Improve the SINR performance
      - Necessitate increased signaling to exchange the RIP measurements among the cells

Part II: Handover Decision for femtocells in LTE-Advanced

- Classification of Handover Decision Algorithms
  - *Energy-efficient algorithms* [60]
    - Utilize the energy saving potential offered by the femtocell infrastructure
    - Energy-efficient parameters include
      - UE battery time, expected UE energy consumption per bit, mean UE transmit power
    - Energy-efficiency and interference-awareness closely related

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Thanks for your kind attention!

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