Component and System-Level Energy Saving for femtocells in Future Mobile Heterogeneous Networks

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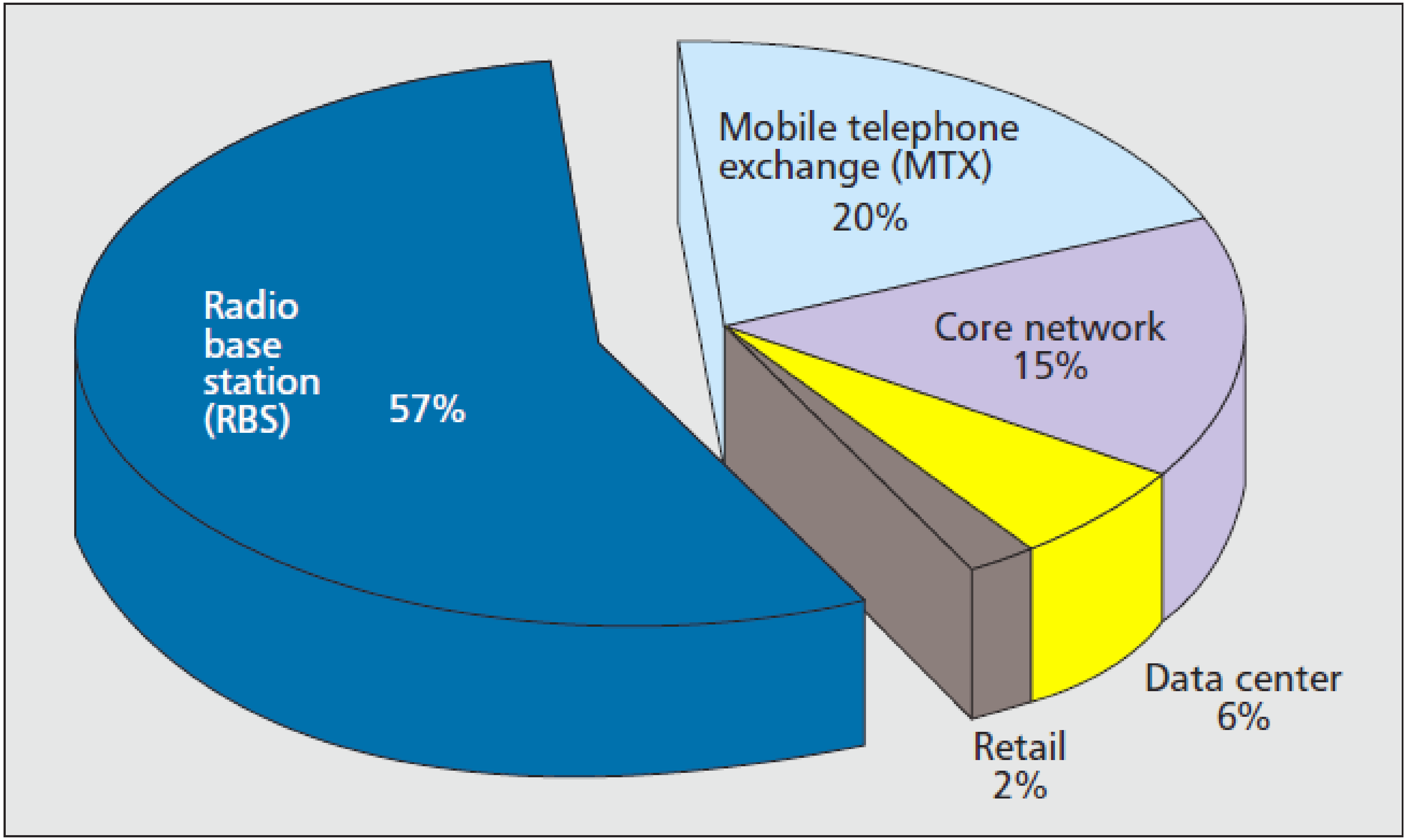
References

- This presentation is based on the following references
  - B. Debaillie, A. Giry, M.J. Gonzalez, L. Dussopt, M. Li, D. Ferling, V. Giannini, "**Opportunities for energy savings in pico/femto-cell base-stations**", 2011 Future Netw. & Mob. Summit (FutureNetw), vol., no., pp.1-8, June 2011.
  - T. Chen, Y. Yang, H. Zhang, H. Kim, K. Horneman, "**Network energy saving technologies for green wireless access networks**", IEEE Wirel. Comm., vol.18, no.5, pp.30-38, Oct. 2011.

Introduction

- Mobile industry faces a critical energy consumption challenge
  - More wireless infrastructure has to be deployed
    - Smart-phones will exceed 1.82 billion units by 2013
    - Network load increases 10-fold every five years
      - Energy consumption increase of 16-20%
  - Mobile communications contribute 15-20% of the entire ICT energy footprint
    - 0.3-0.4 % of global CO2 emissions
  - Need for energy-efficient wireless networking

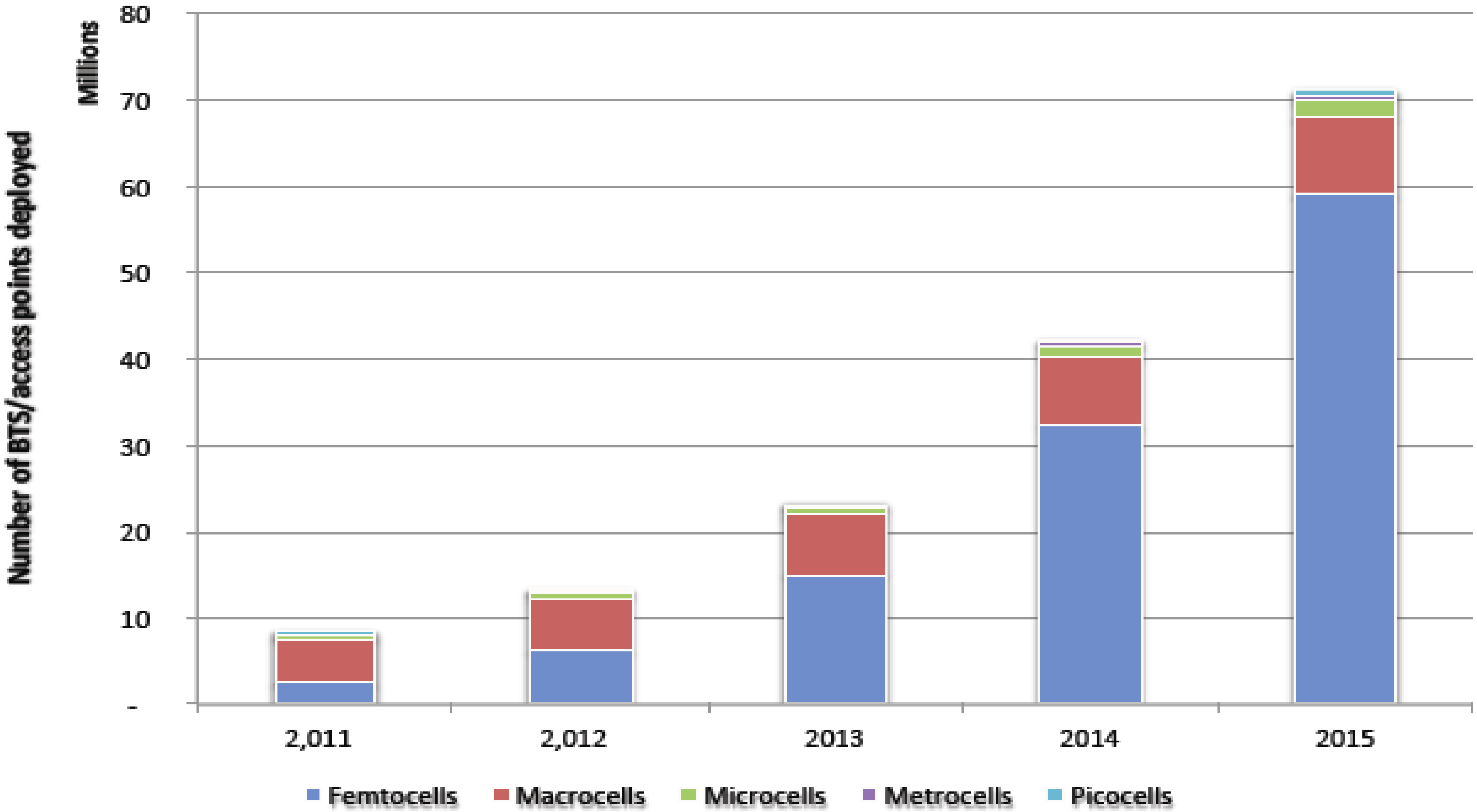
Energy consumption composition of a mobile operator



Radio Access Network

- Radio Access Network: The key energy contributor for a mobile operator
- Motivation for focusing on ES for the RAN
  - Wireless standards traditionally focus on maximizing the user throughput
    - Performance trade-offs: Energy Efficiency (EE) vs Throughput
  - Mobile users urgently ask for enhanced EE
    - Enjoy better mobile services and improve their Quality of Experience (QoE)
  - Provides a big energy saving pool
- Key issues
  - How will the cellular RAN evolve?
  - How to model the EE of a RBS?

How will the cellular RAN evolve?



Informa Telecoms & Media, "Small Cell Market Status", Small Cell Forum, Feb. 2012

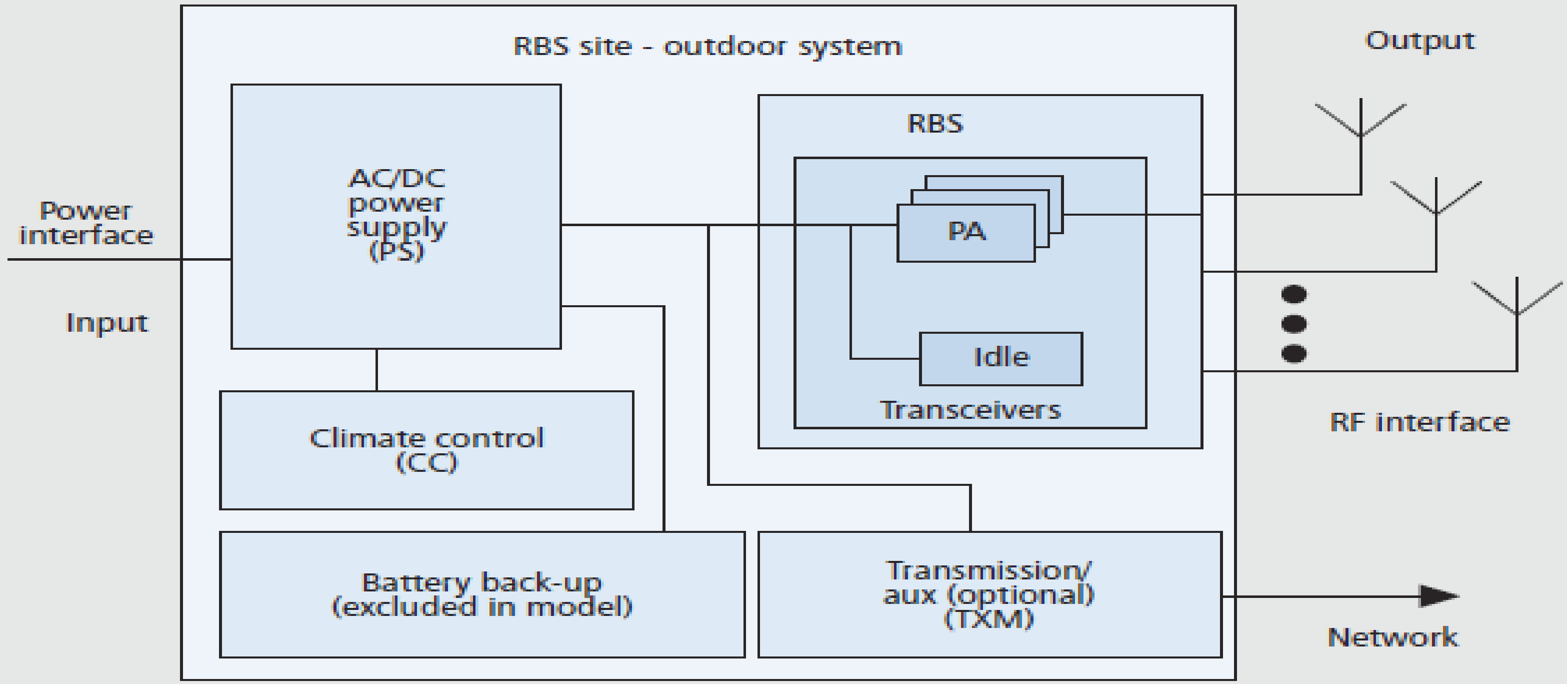
Forecasts for cellular deployment

- Femtocell Market Status
  - 10-fold increase in the number of deployed femtocells from 2012 to 2015
  - The number of deployed femtocells will surpass that of deployed macrocells by six times
- ES for femtocells is challenging
  - Femtocells are deployed and managed by the consumer
  - Unplanned deployment
  - Dense and overlapping deployment
  - Plug and play operation – self-x operation

How to model the EE of a RBS?

- ETSI EE model for outdoor RBS
  - RBS equipment
    - Serves one or more interfaces to the mobile device
    - Radio transceivers: Responsible for transmission and reception of radio signals, include RF Power Amplifiers (PA)
      - The PA amplifies the signal for transmission via antenna
      - In case of no traffic load, the RBS equipment could enter the idle mode (ES)
  - Support systems for the RBS
    - Power Supply (PS)
      - Connects to the AC power line or battery, and offers electrical energy to the equipment
    - Climate Control
      - Maintains the operating climate of the equipment within a defined range
    - Transmission Module (TXM)
      - Connects the RBS to the core network
    - Battery backup
      - Supplies energy to the RBS when the AC power line is down

ETSI EE model for an outdoor RBS



Examples of power consumption values of RBS (unit: watt)

	Input	PS	TXM	RBS*	CC	Output	EE
GSM	3802	602	300	2400	500	120	3.1%
3G	300	20	110	150	20	60	20%

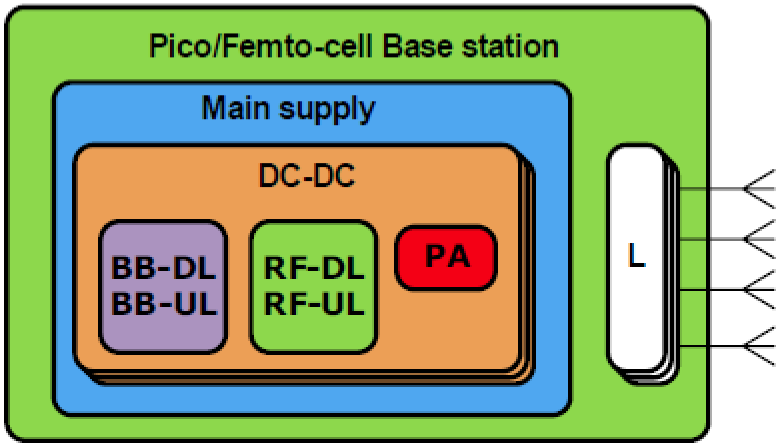
*PA of RBS in GSM consumes 1320 watt power

- EE is defined as the ratio of the radiated to the feeding power

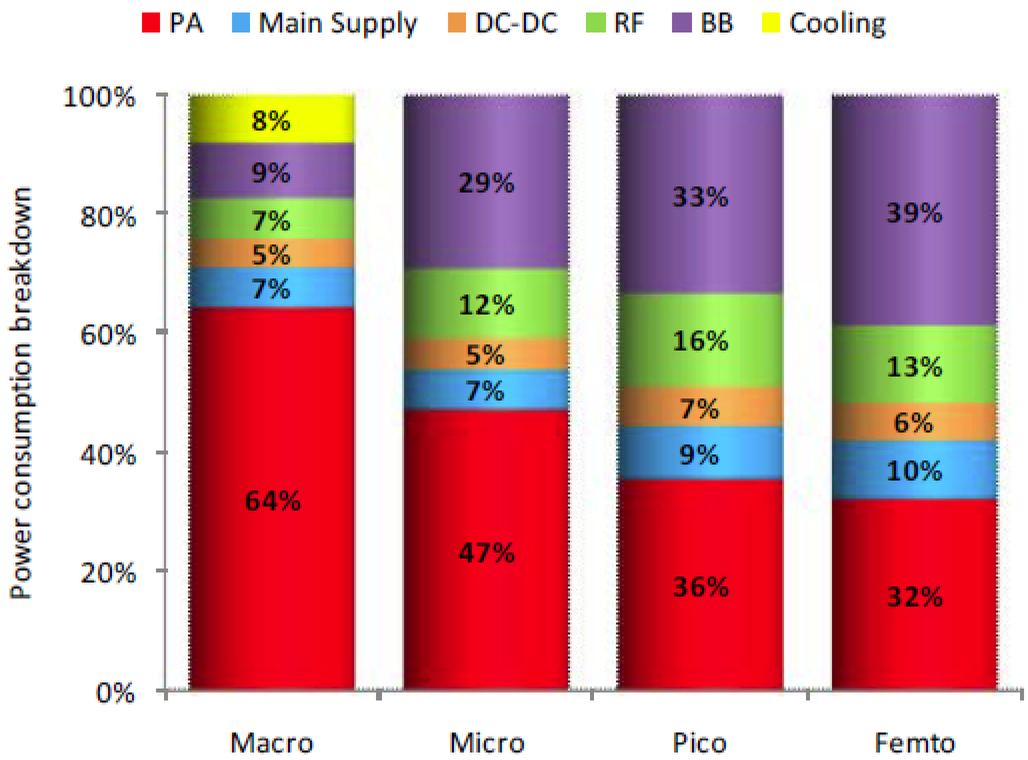
RAN Energy Saving Approaches

- Radio Access Network
  - Energy Saving approaches for femtocells
    - Component-level energy saving
      - Optimize the performance of the various (hardware) components of the femtocell
        - » Digital Baseband Engine, Power Amplifier, Analog RF transmitter, matching network
    - System-level energy saving
      - Modify some of the fundamental network parameters to save energy
        - » Cell bandwidth, number of carriers, number of antennas, Number/density of cellular stations in the network

Component-Level Energy Saving for femtocells



Simplified block diagram of a pico/femto-cell base-station

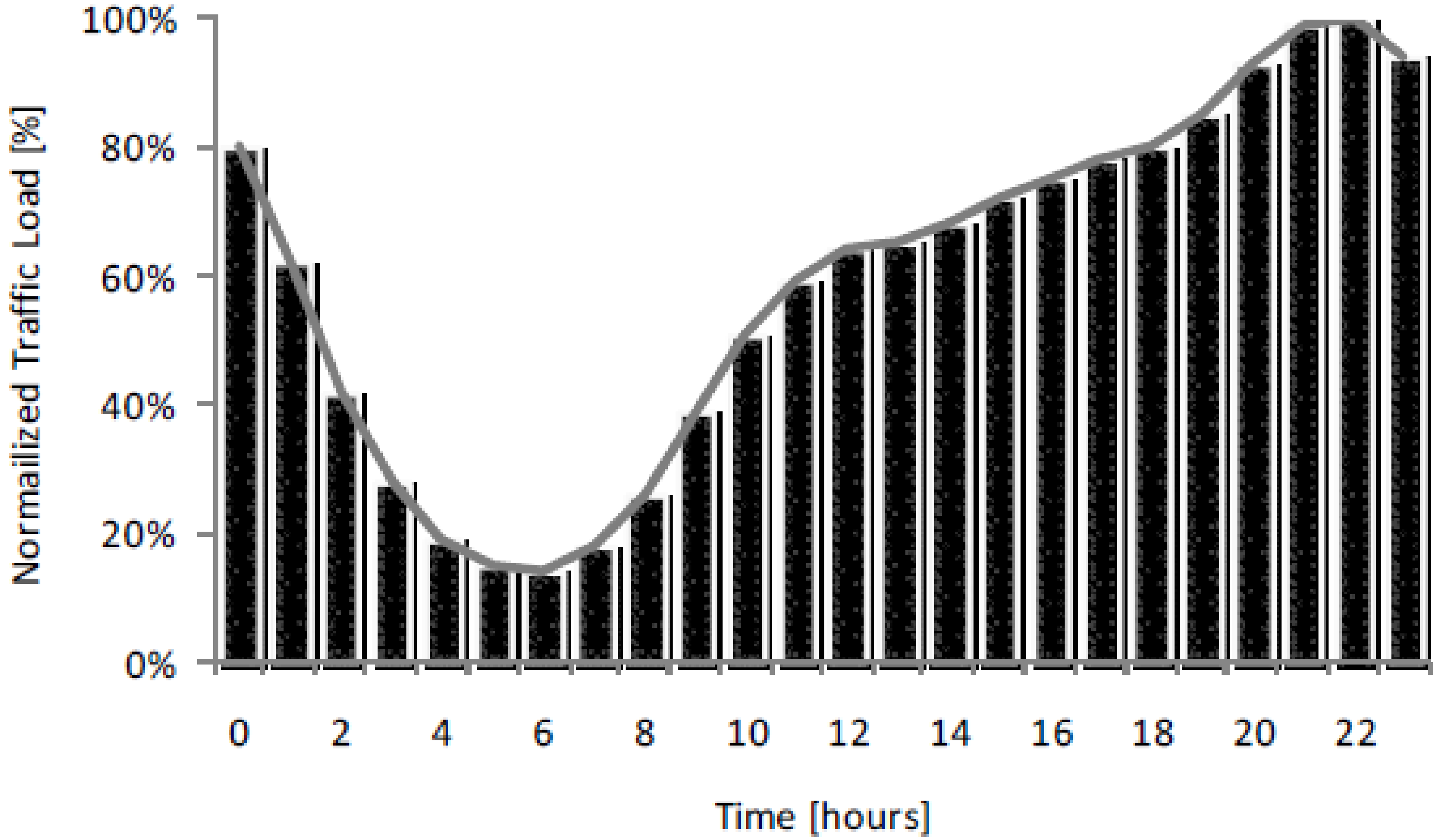


RBS power consumption breakdown for different cell-sizes

Component-Level Energy Saving Opportunities

- Base-stations are designed for serving high traffic load and achieve their maximum performance
- The daily data traffic profile for cellular systems in a dense urban environment shows high variations
  - The highest utilization is observed between 18.00 and 24.00

Daily (24h) data traffic profile for cellular systems (Dense urban)

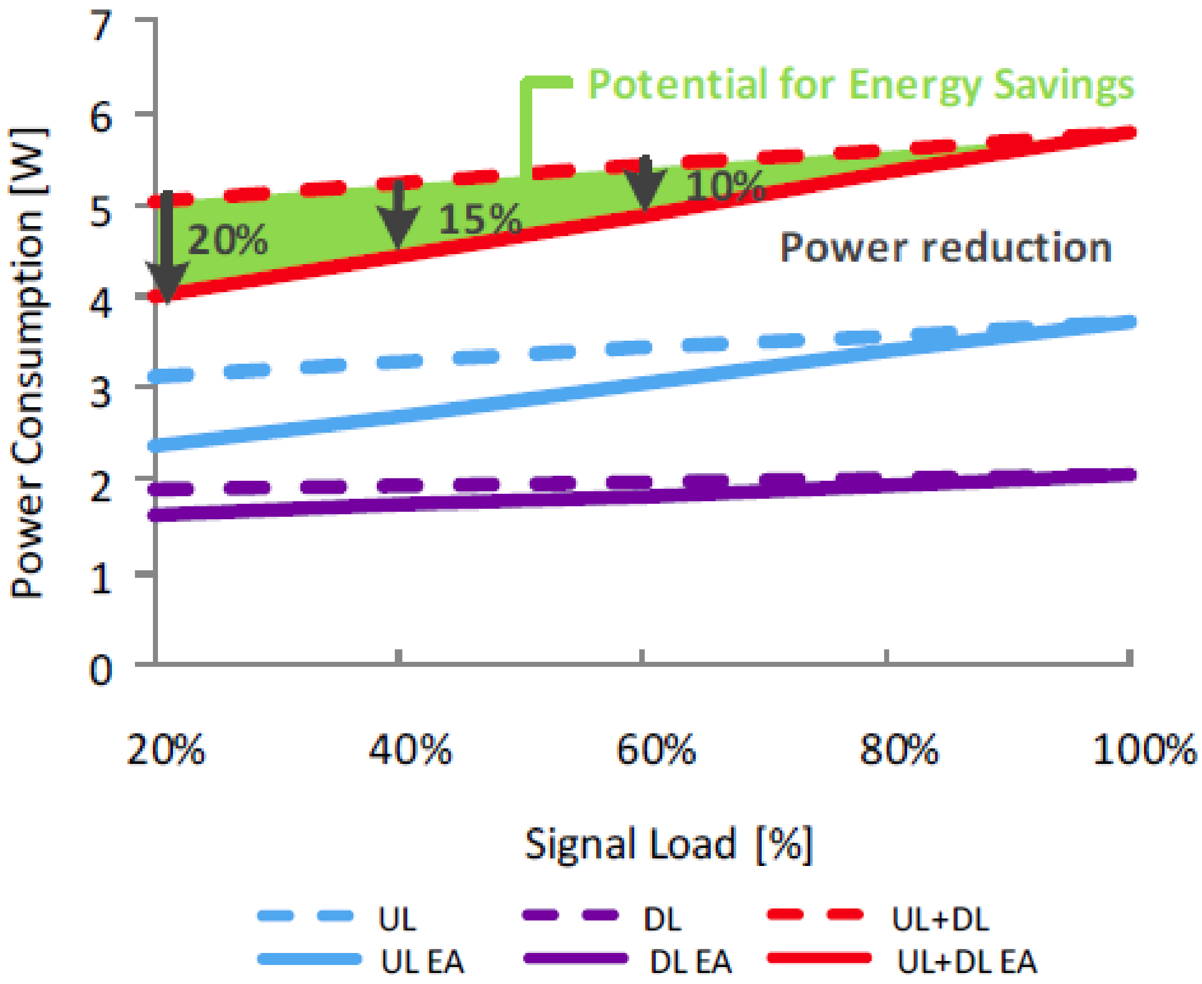


Key idea: Adapt the operation of the various femtocell components with respect to the traffic load

Component-Level Energy Saving: Digital Baseband Engine (DBE)

- DBE functionality
  - Frequency-domain processing for modulation/ demodulation or equalization, channel coding/decoding, pre-distortion, platform control and backbone network serial link
- The energy consumption of the DBE is becoming more and more dominant
  - Due to the shrinking cell size and the rapidly growing signal processing complexity
- Enable energy scalability depending on the signal load
  - Bandwidth, modulation, coding rate, number of antennas, duty-cycling in time or frequency

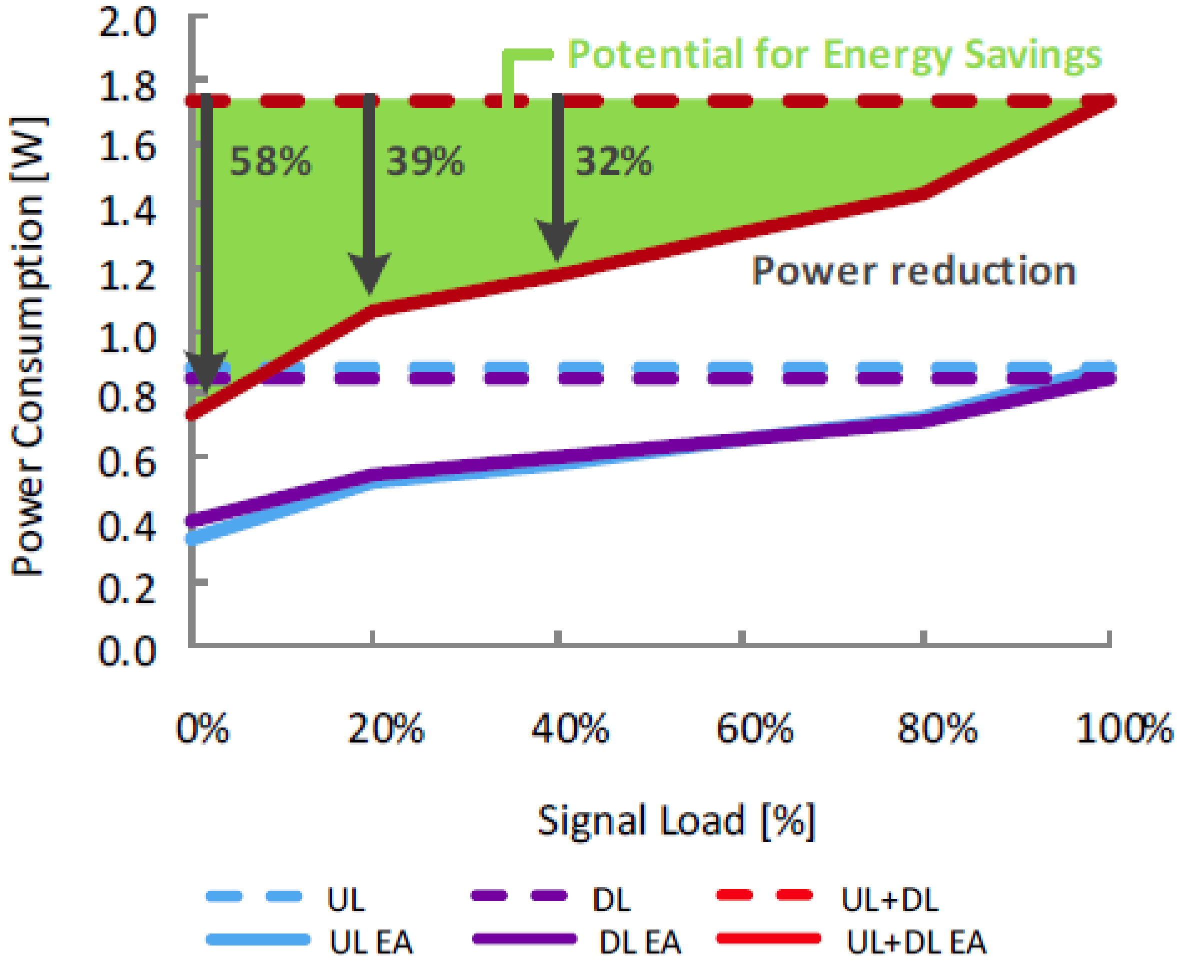
Component-Level Energy Saving: Digital Baseband Engine



Component-Level Energy Saving: RF Transceiver

- The RF transceiver of traditional base-stations, targets to achieve the best SiNAD performance independent of the signal load
  - **Signal-to-noise and distortion ratio** (**SiNAD**) is a measure of the quality of a signal from a communications device
- Scale the transceiver to provide a 'just good enough' SiNAD performance depending on the current signal load (SDR technology)

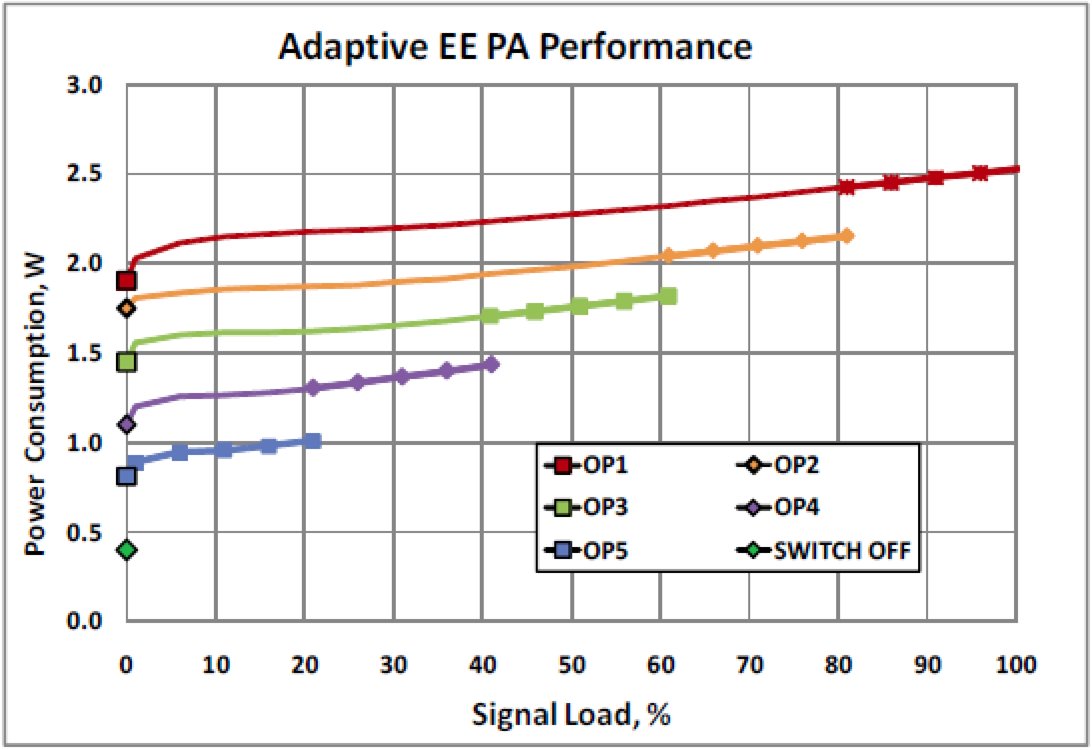
Component-Level Energy Saving: RF Transceiver



Component-Level Energy Saving: Power Amplifier

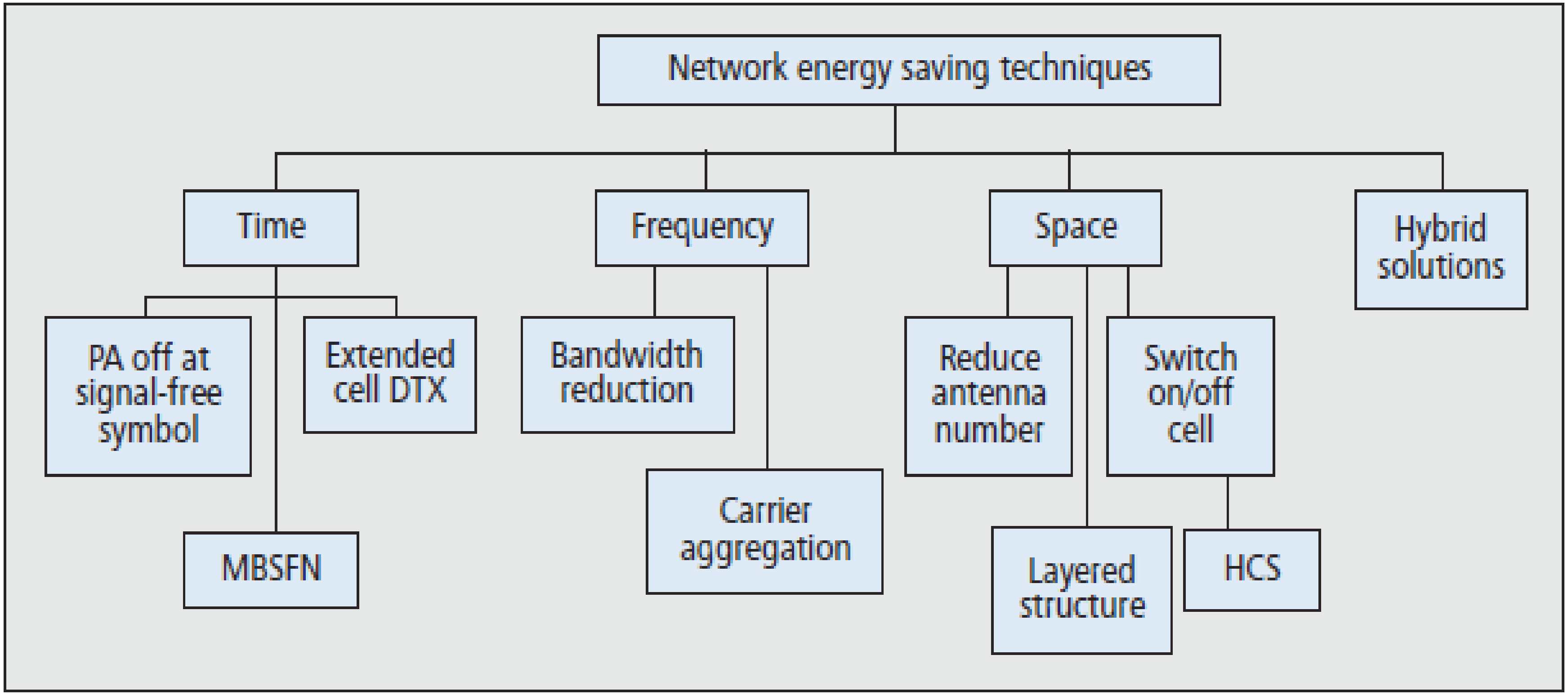
- The PA is not the major energy consumption contributor in femtocells
- Adaptive Energy Efficient Power Amplifier
  - Adjust the PA Operating Point
    - The PA operating point can be optimized according to the required RF output power level (traffic load), while fulfilling the spectral mask and PAPR specifications
  - Enable fast switching on/off of the RF power transistor
    - Minimum consumption when no RF output power is required

Component-Level Energy Saving: Power Amplifier



- OP5: <20% load, OP4:20%-40% load, OP3: 40%-60% load, OP2: 60%-80% load, OP1: 80%-100% load

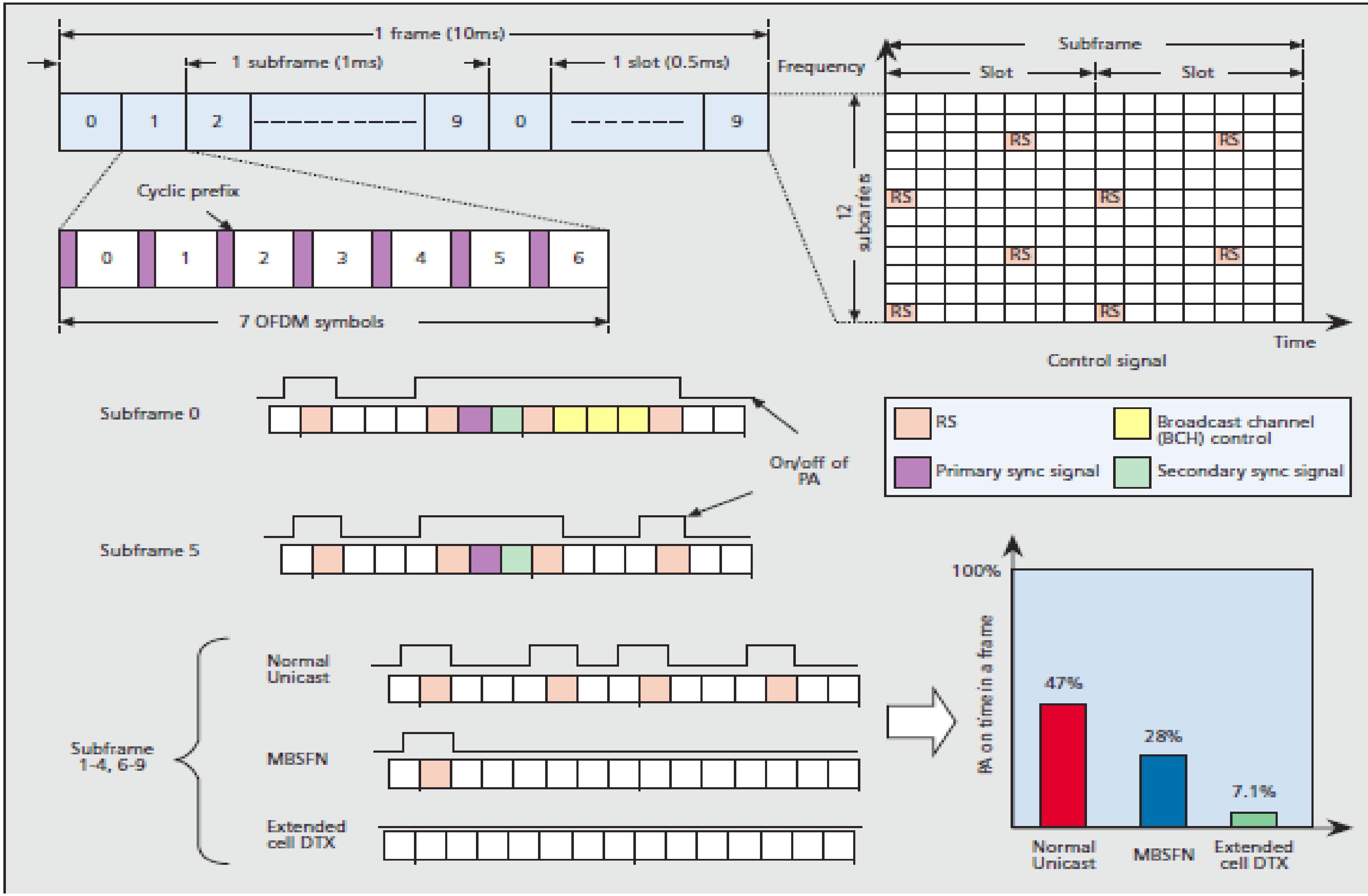
System-Level Energy Saving



System-Level Energy Saving: Time domain

- Time domain solutions temporally shut down PAs in a RBS when there is no data traffic in the downlink
  - Tightly related to the frame structure of the cellular system
  - Three basic ways to temporally shut down PAs
    - Turning off a PA in signal-free symbols
    - Using a multicast broadcast single frequency network (MBSFN) subframe to reduce RSs
    - Use the extended cell discontinuous transmission (DTX) to further reduce the number of RSs

System-Level Energy Saving: Time domain



System-Level Energy Saving: Time domain

- PA Off at Signal-Free Symbol
  - Turn off PAs in time periods of a slot where downlink symbols are signal-free
  - Signal-free periods do not include DL RSs and control signals
  - Assuming it takes half of a symbol time to turn on a PA but the PA can be immediately turned off: The PA is only required to be on for at least 47% of the time in a frame

System-Level Energy Saving: Time domain

- Utilize the MBSFN frame structure
  - MBSFN is proposed to deliver services such as mobile TV using the LTE infrastructure
  - In an MBSFN frame, the symbols for RS in subframes 1–4 and 6–9 are reduced to 1
  - Use the MBSFN structure to further reduce the number of RSs
    - The PA operating time during a frame is then reduced to 28 percent

System-Level Energy Saving: Time domain

- Utilize the Extended Cell DTX mode (3GPP)
  - The extended cell DTX allows to further reduce RSs compared to the MBSFN approach
  - If there is no downlink traffic, in the extended cell DTX mode there is no need to have any transmission in subframes 1–4 and 6–9 of a frame
  - The PA operating time in a frame is further reduced to 7.1 percent

System-Level Energy Saving: Time domain

- Advantages
  - Significantly reduce the PA operation time when a cell is idle (apply better in rural areas)
  - Need for joint time-frequency domain scheduling to make them effective in urban areas as well, and only under low traffic conditions
- Disadvantages
  - Without enough RSs, some UEs may experience unpredictable problems synchronizing with an RBS or decoding control signals
  - Reducing RSs may also prevent UE from entering into terminal DTX mode and thus shorten its battery life

System-Level Energy Saving: Frequency domain

- Bandwidth Reduction
  - Existing cellular systems allow for scalable bandwidth utilization
  - Adapt the cell bandwidth depending on the downlink traffic load
    - Lower the overall transmit power and reduce the number of DL RSs
  - This approach is suitable only for low traffic
  - Marginal gains given that the PA is still active

System-Level Energy Saving: Frequency domain

- Carrier Aggregation
  - Shut down the associated PAs when the corresponding aggregated carriers are not scheduled for the downlink traffic
  - Applicable to an RBS that has aggregated carriers and separate PAs attached to each group of carriers

System-Level Energy Saving: Frequency domain

- Advantages
  - Frequency domain approaches are backwards compatible and easy to implement at the RBS
- Disadvantages
  - Can only be deployed for low traffic
  - Result in marginal EE gains

System-Level Energy Saving: Spatial domain

- Time and frequency domain approaches are employed in a single RBS
- Spatial domain the solutions can be extended to heterogeneous networks, and are therefore more flexible
  - Reduce the Antenna Number
  - Switch On/Off Cells
  - Layered Structure (Heterogeneous Networking)

System-Level Energy Saving: Spatial domain

- Reducing the antenna number
  - The most commonly used energy saving technique in the spatial domain
  - Can be used when the traffic load of a cell is low
  - Advantages
    - Decreases the total output power and shrinks the cell size
    - For example, if the branches of antennas are reduced from 4 to 1, energy consumption of transceivers is reduced to 1/4, as the PAs associated with those branches can be switched off
  - Disadvantages
    - Need to boost the power of RSs and control signals so as to maintain the cell size
    - May lead to service degradation or interruption as the antenna reconfiguration is needed
    - The change of the antenna number should notify UEs properly

System-Level Energy Saving: Spatial domain

- Switch On/Off Cell
  - A system-level approach that works in an area covered by multiple (and overlapping) cells
    - When the traffic load in a given area is low, some cells can be shut down, and the served UE units are handed over to the remaining cells
    - Those inactive cells can be turned on during the busy time autonomously or based on signals by active neighbor cells or from the core network (OAM module)
  - Advantages
    - Attains maximum energy saving
    - No need to modify the low-layer components in the RBS
    - Provides a good balance between network performance and energy saving
  - Limitations
    - Frequent switching on/off cells affects the UE services
    - Reduce the battery life of the served UEs as they have to connect with other cells far away (Reduced network density)
    - If there is no overlapping between cells, the remaining active cells need to increase their power to cover this area, (perhaps) neutralizing the energy saving gain

System-Level Energy Saving: Spatial domain

- Layered Structure
  - Applies to heterogeneous multi-tier networks
    - Prioritized access to low-power nodes
      - E.g., prioritized access to the femtocell station
  - Advantages
    - Provides energy saving opportunities for the RBS of higher layers
      - More energy consuming in general
    - Prolongs the UE battery lifetime
      - Lower tiers are typically characterized by low-power operation and short cell radii
  - Disadvantages
    - Requires for more sophisticated admission control and mobility management algorithms
      - Lower tiers are characterized by random deployment and short cell radii

System-Level Energy Saving: Hybrid Solutions

- Hybrid solutions
  - Combine solutions in different domains to adapt energy consumption of an RBS in different traffic conditions
  - Achieve the highest ES gain
  - Ask for increased processing/interruption time and signaling for system reconfiguration
  - Need to anticipate their impact on the UE performance

System-Level Energy Saving: Research Directions

- Account for the total energy consumed in the life-cycle of the system
  - Include the energy consumed in the use phase of a system and the energy used to manufacture telecom equipment
- Investigate the impact of introducing any new architecture and device to the overall EE improvement
  - The optimization of EE at one point of the system may lead to suboptimal results at other points
- Attain a good trade-off between optimizing the QoS performance and achieving high energy saving gains
  - The improvement of EE should not compromise the supported QoS

System-Level Energy Saving: Research Directions

- Propose comprehensive energy consumption models
  - Capture the key variables of a system regarding energy consumption while providing sufficient abstraction
- Use appropriate metrics to evaluate the performance of the proposed ES technique
  - The EE metric is normally defined as a performance per unit of energy, and the performance typically refers to throughput
  - Capture the provided QoS by accounting QoS measures other than the end throughput
- Optimize the functionality of the system under a EE perspective
  - The EE problem at the system level can be modeled as a joint optimization problem which takes into account resource allocation in time, frequency and spatial domain

Thanks for your kind attention!

Questions?

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