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Chapter 10: Introduction to Green Cellular Networks

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Global climate change/ The cause of global warming

- Global climate change

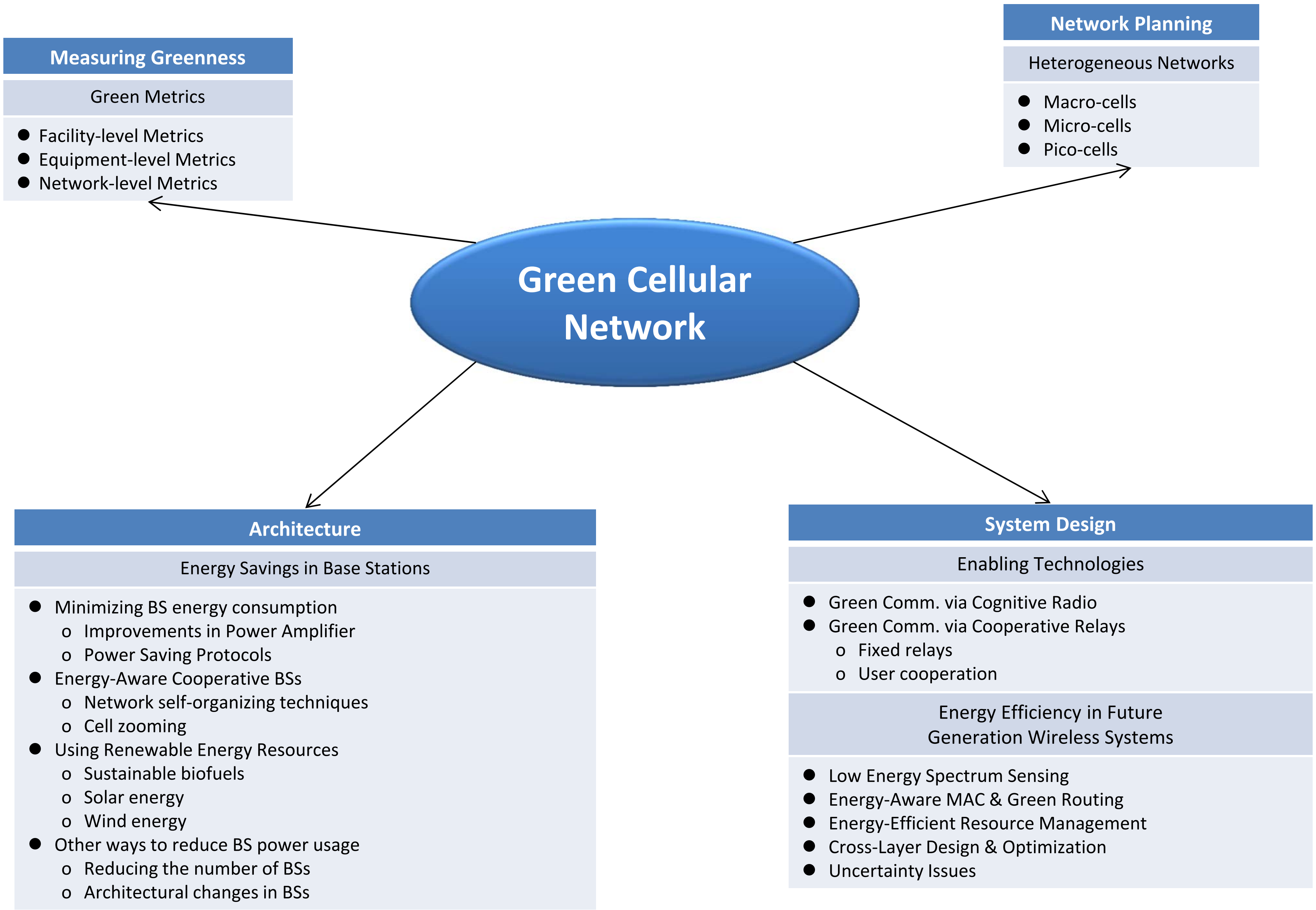


- The cause of global warming

Outline

1. Introduction
2. **Measuring greenness**
3. **Architecture**
4. **Network planning**
5. **System design**
6. Conclusion

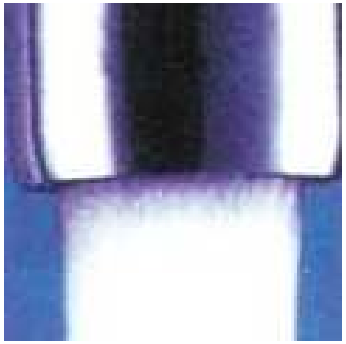
Technical roadmap for Green Cellular Networks: A taxonomy graph

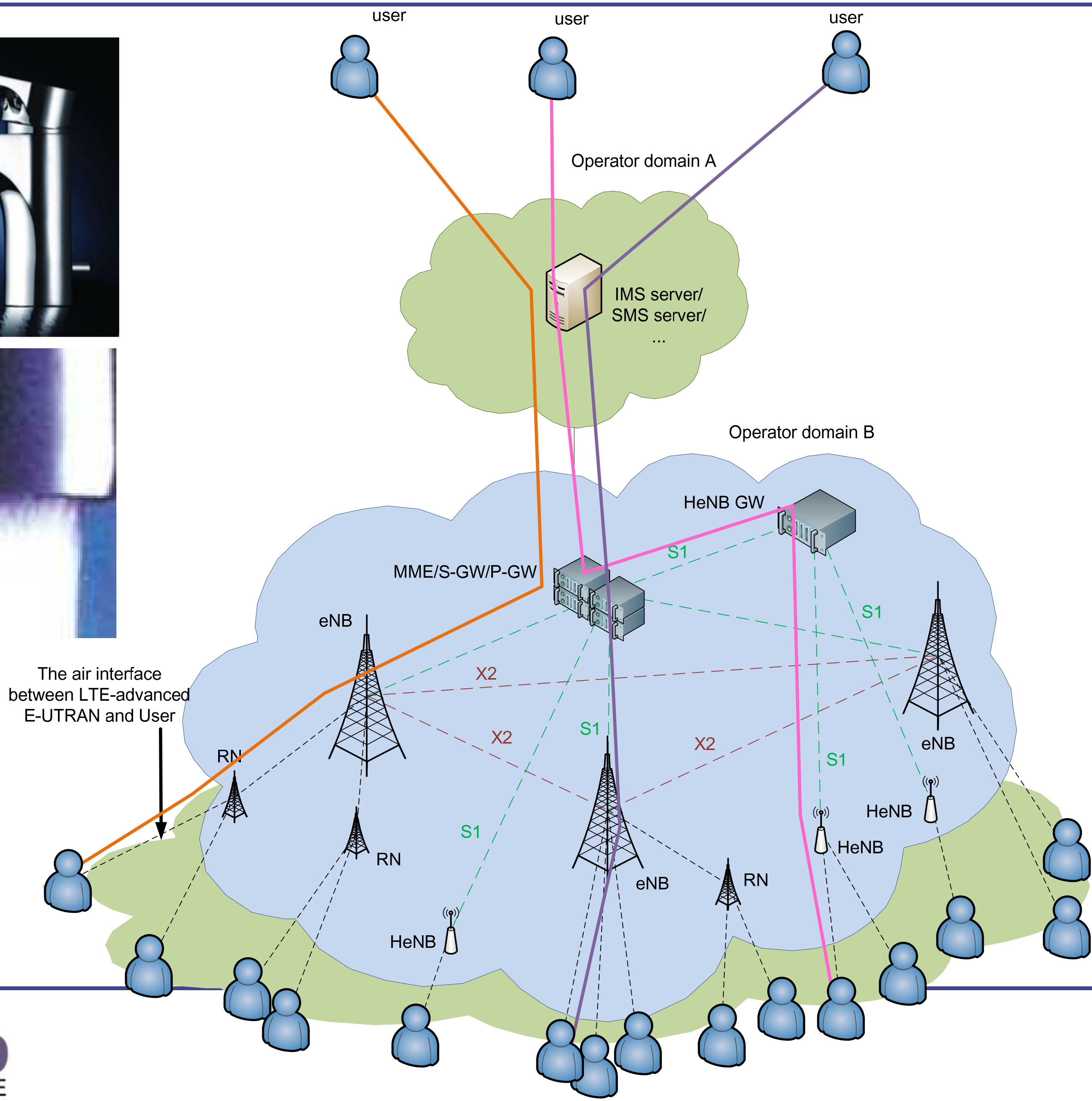


1. Introduction

- During the last decade, there has been tremendous growth in cellular networks market.
- The demand for **cellular data traffic** has also grown significantly in recent years.
  - With the introduction of Android and iPhone devices, use of ebook readers such as iPad and HTC Flyer, and the success of social networking giants such as Facebook.
  - The current wireless networks are mainly designed for **human to human (H2H) communication** mode, which means there are high requirements for mobility and human interactive experience such as call setup delay and quality of service (QoS).
- Mobile operators find meeting these new demands in wireless cellular networks inevitable, while they have to keep their costs minimum.

H2H communication





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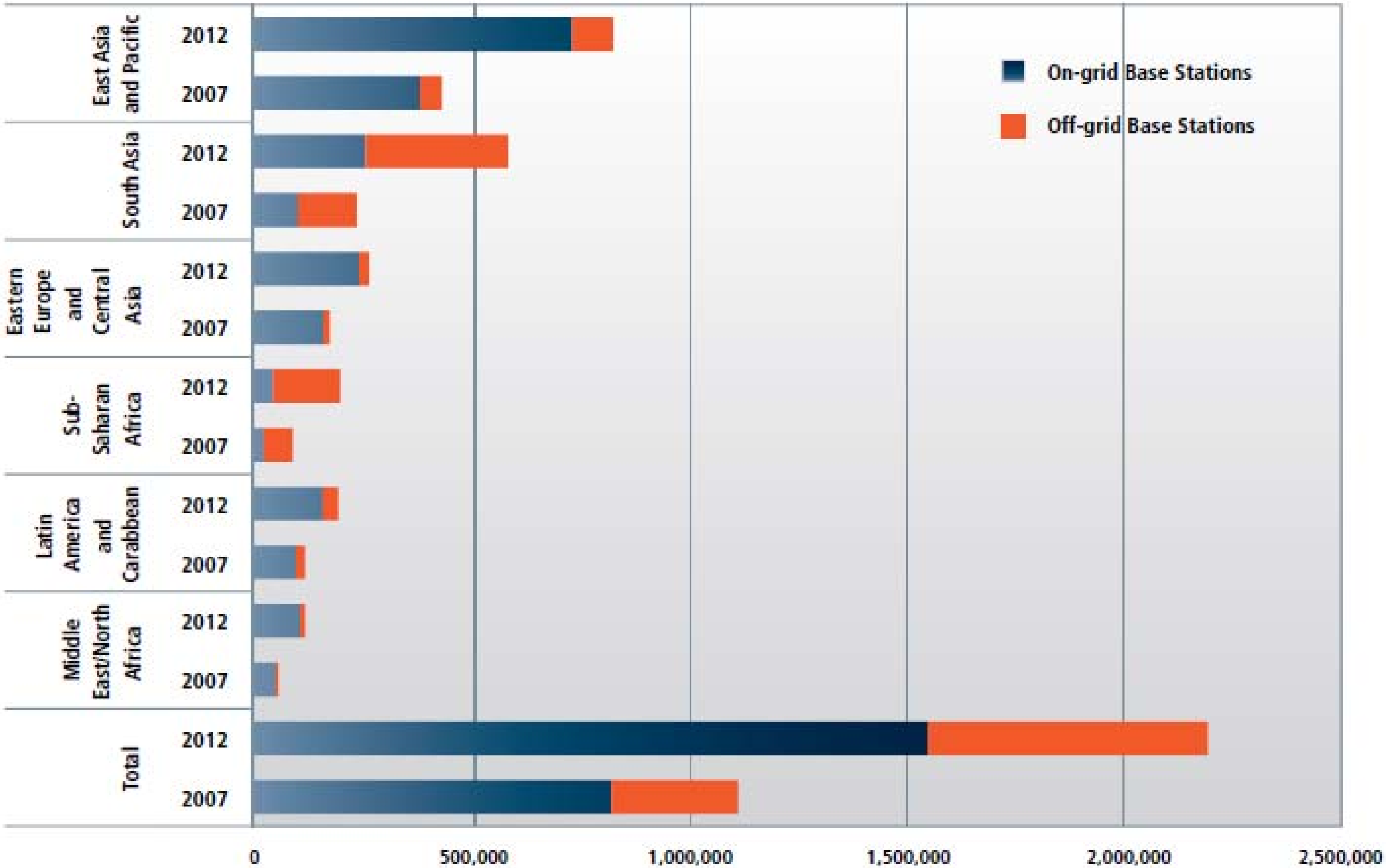
Cont.

- There are currently more than 4 million base stations (BSs) serving mobile users, each consuming an average of 25MWh per year.
- The number of BSs in developing regions are expected to almost double by 2012 as shown in Fig. 1.
- Information and Communication Technology (ICT) already represents around 2% of total carbon emissions.

Fig. 1. Growth in base stations in developing regions 2007-2012 (GSMA research)



Green Cellular Networks

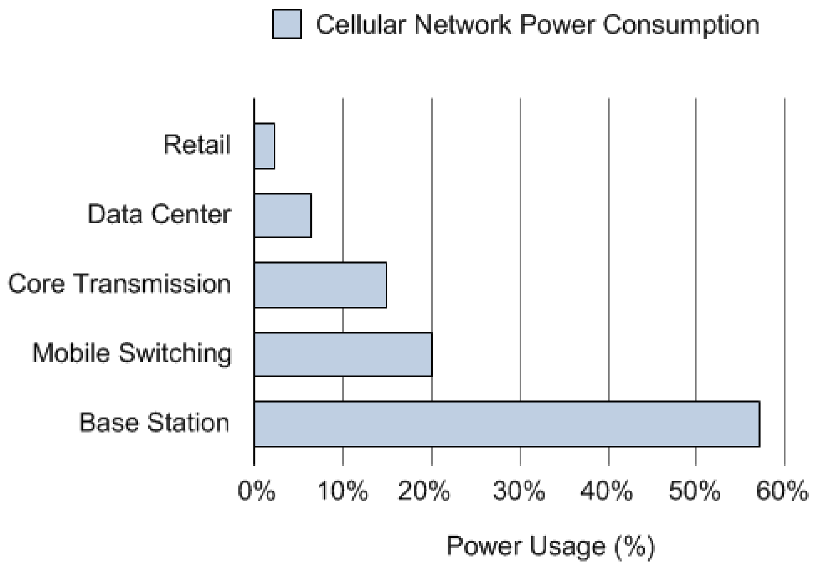
- This trend has stimulated the interest of researchers in an innovative new research area called "Green Cellular Networks".
- **European Commission** has recently started new **projects** within its seventh Framework Programme to address the energy efficiency of mobile communication systems, viz.
  - "Energy Aware Radio and NeTwork TecHnologies (**EARTH**)"
  - "Towards Real Energy-efficient Network Design (**TREND**)"
  - "Cognitive Radio and Cooperative strategies for Power saving in multi-standard wireless devices (**C2POWER**)"
- A typical cellular network consists of three main elements;
  - **A core network** that takes care of switching,
  - **BSs** providing radio frequency interface
  - **The mobile terminals** in order to make voice or data connections.

Global Green ICT Policy: Europe

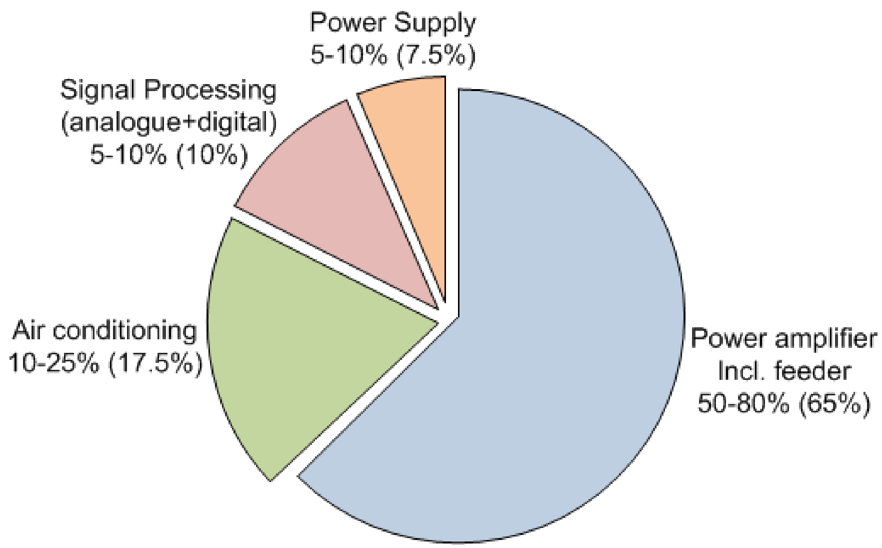
Project	Organizer	Participants	Targets	Working Emphasis
EARTH	European Commission FP7 IP(3 years / 15 million)	European main mobile operators and research organizations	Mobile networks	• energy aware radio and network technology • energy-efficient deployment, architecture, adaptive management• multi-cell cooperation
OPERA-Net	CELTIC / EUREKA(3 years / 5 million)	European main mobile operators	Mobile networks	• heterogeneous broadband wireless network • mobile radio access network • link-level power efficiency, amplifier, test bed
GREEN-T	CELTIC(3 years / 6 million)	European main mobile operators	Mobile networks(particularly 4G)	• multi-standard wireless mobile devices • cognitive radio and cooperative strategies • QoS guarantee

Cont.

- "Green Radio" is a vast research discipline that needs to cover all the layers of the protocol stack and various system architectures.
  - Figure 2 shows a breakdown of power consumption in a typical cellular network and gives us an insight into the possible research avenues for reducing energy consumption in wireless communications.



(a) Power consumption of a typical wireless cellular network [2](ref. therein)

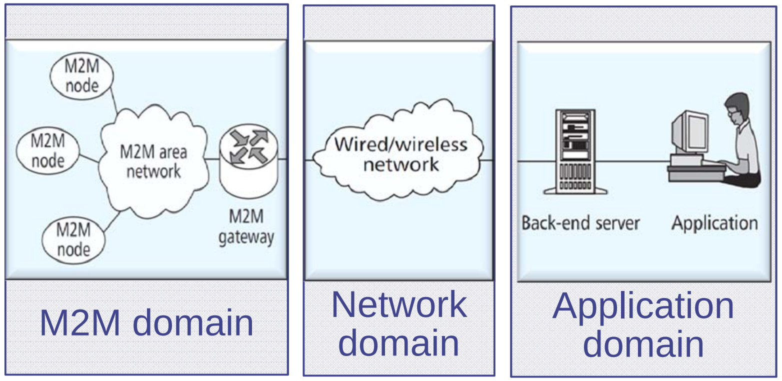


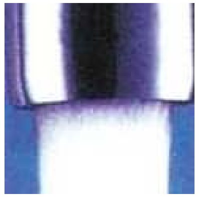
(b) Power consumption distribution in radio base stations [3](ref. therein)

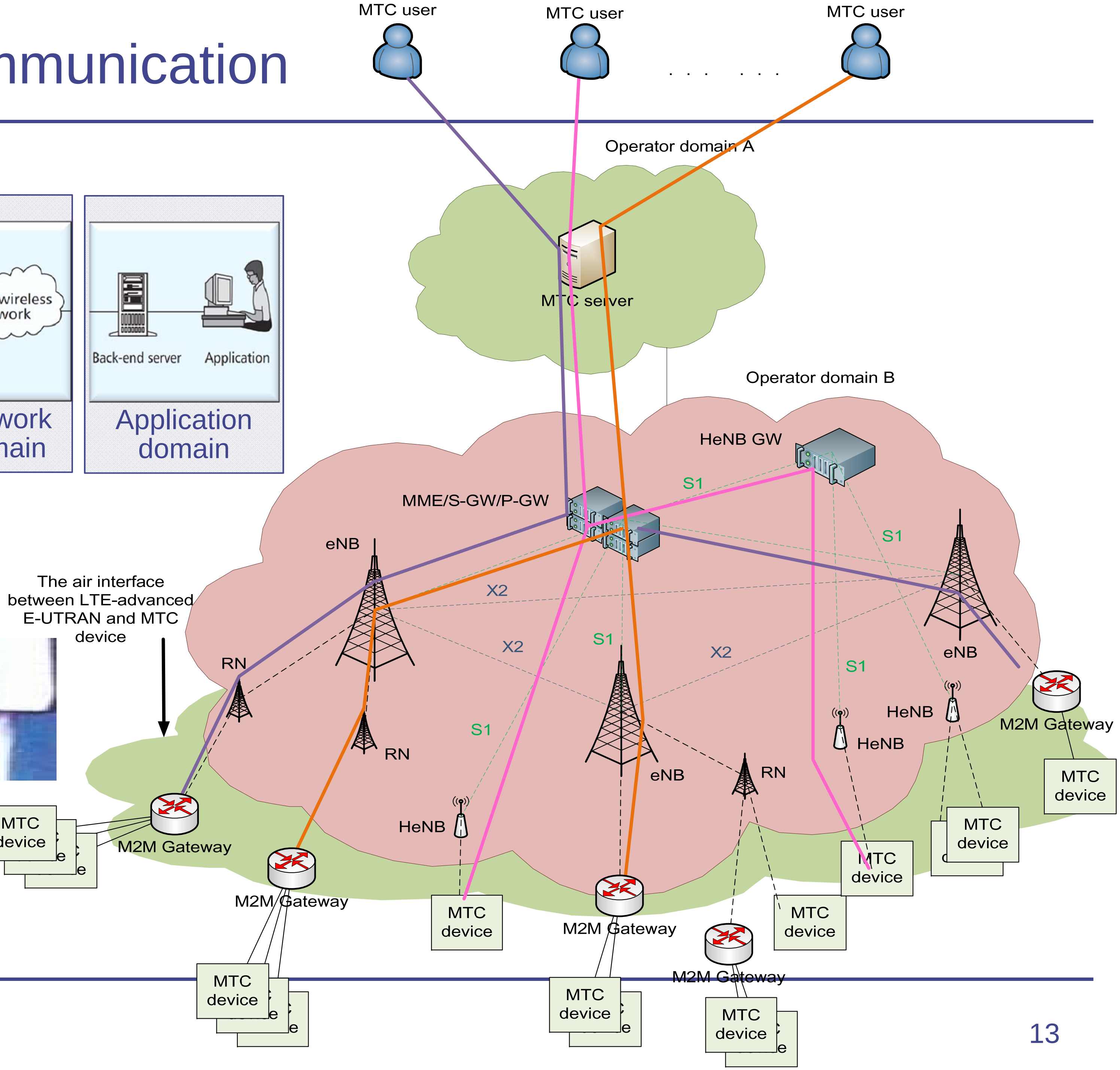
M2M Communication

- Machine to Machine (M2M) communications is seen as a form of data communications between entities that do not necessarily need any form of human intervention.
- It is different from current communication models in the sense that it involves new or different market scenarios, low cost and low effort, **a potentially very large number of communicating terminals**, and **small** and **infrequent traffic transmission** per terminal.
- M2M communications, or **machine-type communications** (**MTC**) as sometimes referred by the Third Generation Partnership Project (3GPP), is enabling a ubiquitous computing environment toward the pervasive Internet.

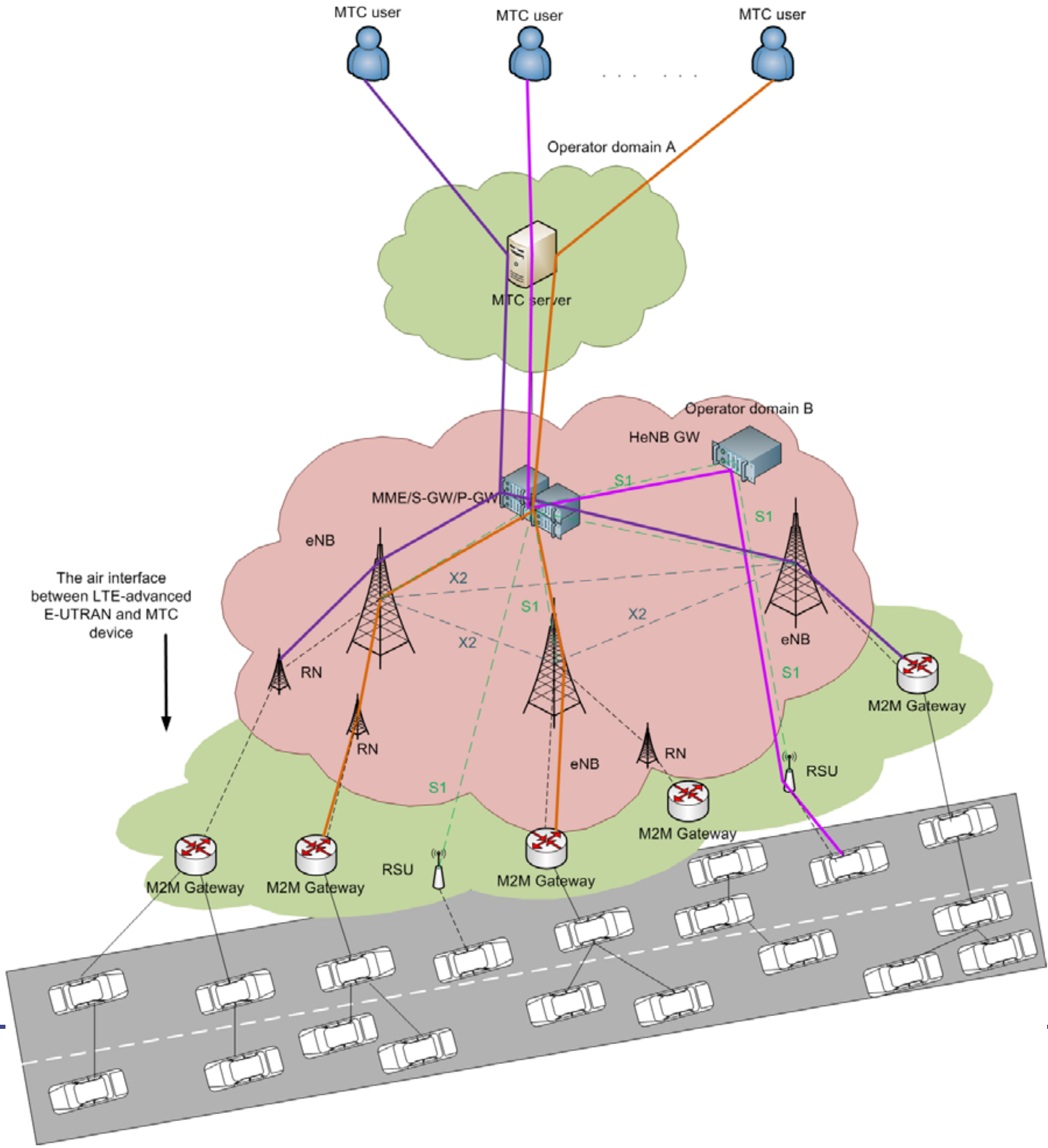
M2M communication







Vehicular M2M communication



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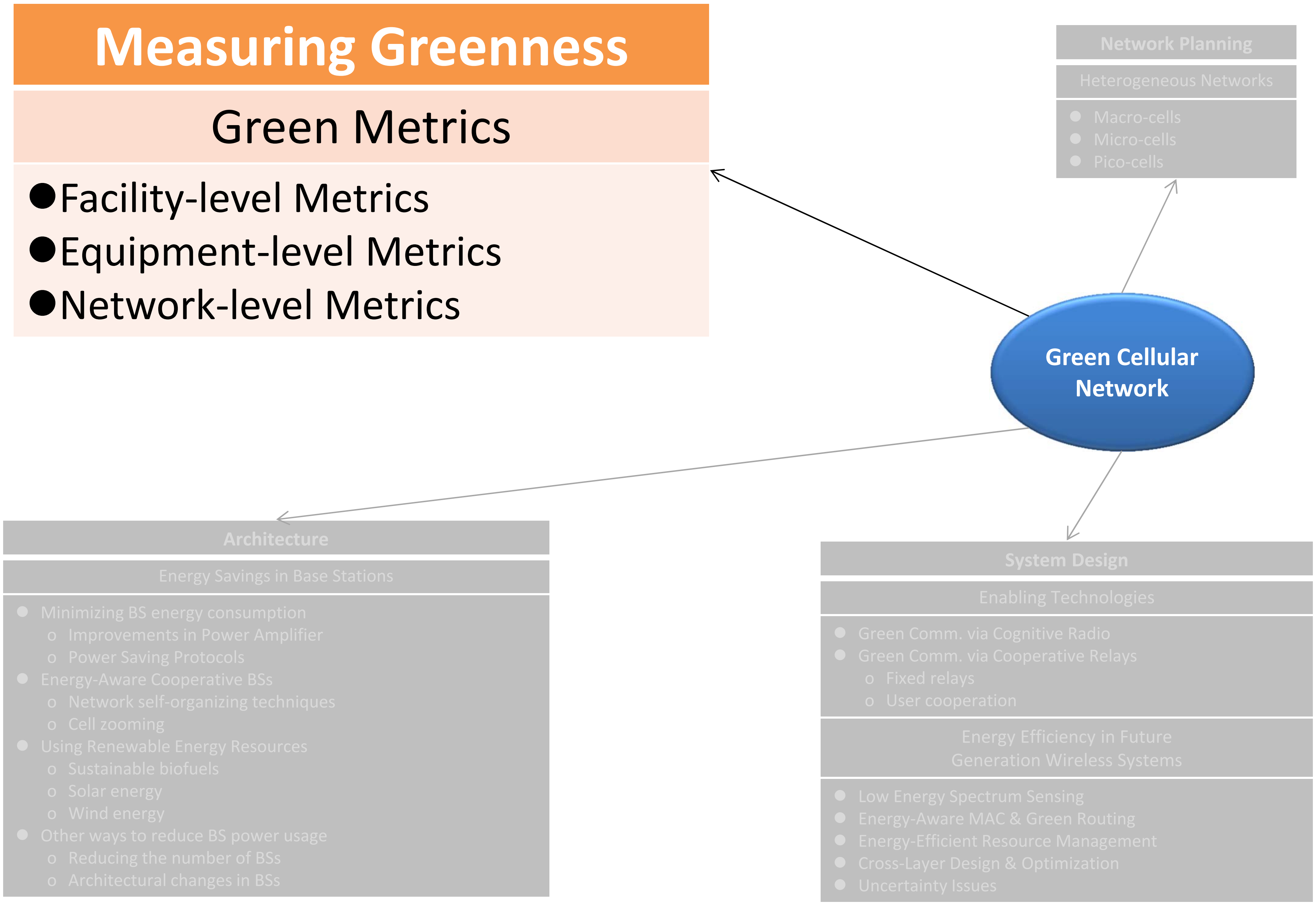
- To address the challenge of increasing power efficiency in future wireless networks, possible technologies
  - Energy efficient wireless architectures and protocols
  - Efficient BS redesign
  - Opportunistic network access
  - Cognitive radio
  - Cooperative relaying
  - Heterogenous network deployment based on smaller cells
  - Smart grids

Green Cellular Network

- **Measuring Greenness**
- Architecture
- Network Planning
- System Design

Technical roadmap for Green Cellular Networks: A taxonomy graph



2. Measuring greenness

- **Facility-level** metrics
  - relates to high-level systems where equipment is deployed (such as datacenters, ISP networks etc.).
- **Equipment level** metrics
  - are defined to evaluate performance of an individual equipment.
- **Network level** metrics
  - assess the performance of equipments while also considering features and properties related to capacity and coverage of the network.

Trade-offs linked with **energy efficiency** and the **overall performance**

- Four key trade-offs of **energy efficiency** with **network performance**
  - **Deployment** efficiency (balancing deployment cost),
  - **Spectrum** efficiency (balancing achievable rate),
  - **Bandwidth** (balancing the bandwidth utilized)
  - **Delay** (balancing average end-to-end service delay).

Relation between energy and performance

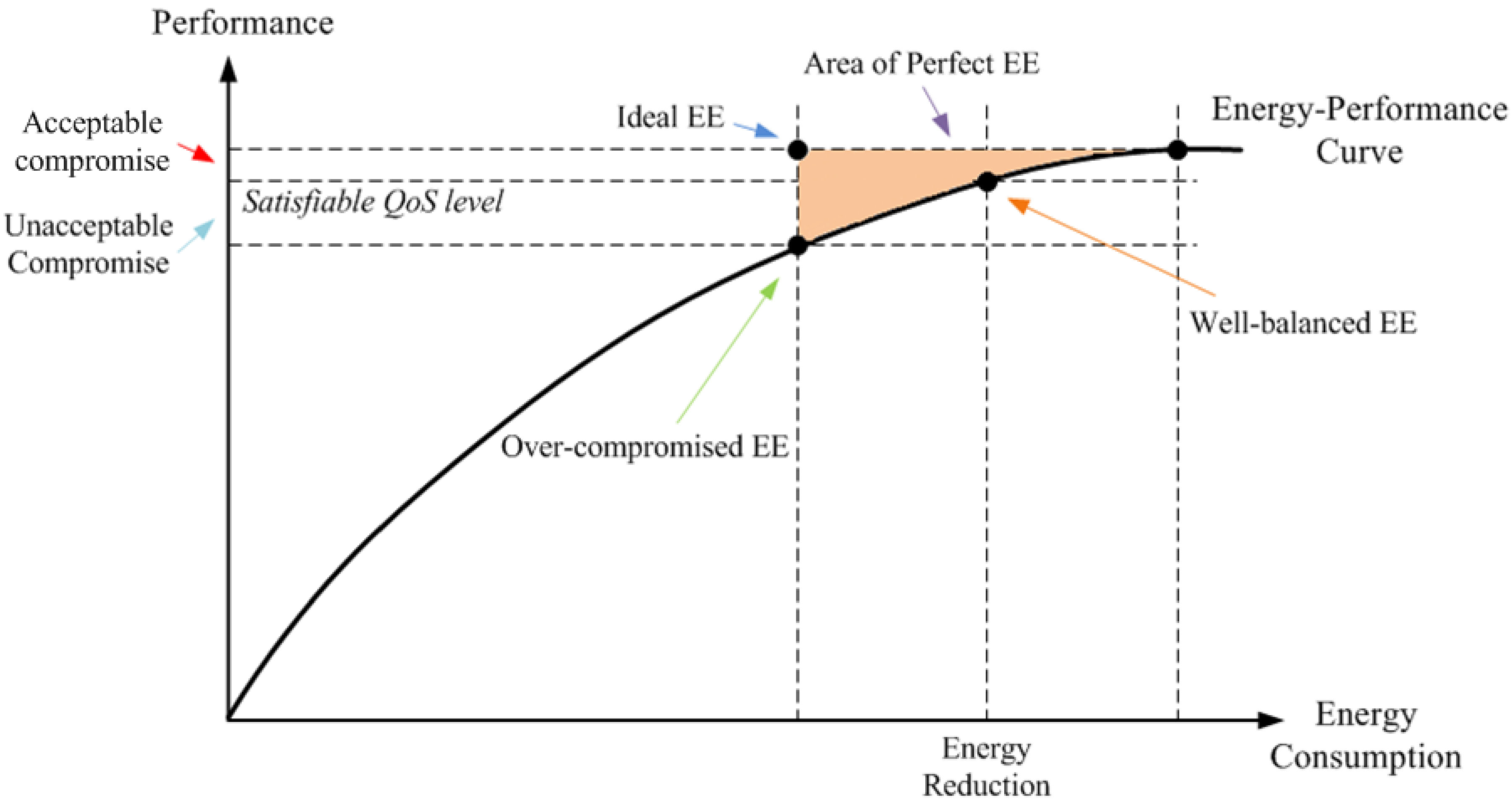


Table I. Some energy efficiency metrics

Metric	Type	Units	Description
PUE (Power Usage Efficiency)	Facility-Level	Ratio ($\geq$1)	Defined as ratio of total facility power consumption to total equipment power consumption.
DCE (Data Center Efficiency)	Facility-Level	Percentage	Defined as reciprocal of PUE.
Telecommunications Energy Efficiency Ratio (TEER)	Equipment-Level	Gbps/Watt	Ratio of useful work to power consumption
Telecommunications Equipment Energy Efficiency Rating (TEEER)	Equipment-Level	$-\log\left(\frac{\text{Gbps}}{\text{Watt}}\right)$	$-\log\left(\frac{P_{\text{total}}}{\text{Throughput}}\right)$, where P_{total} is given by equation (1)
Energy Consumption Rating (ECR)	Equipment-Level	Watt/Gbps	Ratio of energy consumption over effective system capacity
ECR-Weighted (ECRW)	Equipment-Level	Watt/Gbps	Calculated the same way as ECR except energy consumption is now calculated as $0.35E_f + 0.4E_h + 0.25E_i$, where each term corresponds to energy consumption in full load, half load and idle modes.
ECR-variable-load metric (ECR-VL)	Equipment-Level	Watt/Gbps	Average energy rating in a reference network described by an array of utilization weights [16].
ECR-extended-idle metric (ECR-EX)	Equipment-Level	Watt/Gbps	Average energy rating in a reference network, where extended energy savings capabilities are enabled [16].
Performance Indicator in rural areas (PI_{rural})	Network-Level	km^2/Watt	Ratio of total coverage area to power consumed at site as given by eq. (3)
Performance Indicator in urban areas (PI_{urban})	Network-Level	users/Watt	Ratio of number of subscribers to power consumed at the site as given by eq. (4)

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- Measuring Greenness
- **Architecture**
- Network Planning
- System Design

Technical roadmap for Green Cellular Networks: A taxonomy graph

Architecture

Energy Savings in Base Stations

- Minimizing BS energy consumption
  - Improvements in Power Amplifier
  - Power Saving Protocols
- Energy-Aware Cooperative BSs
  - Network self-organizing techniques
  - Cell zooming
- Using Renewable Energy Resources
  - Sustainable biofuels
  - Solar energy
  - Wind energy
- Other ways to reduce BS power usage
  - Reducing the number of BSs
  - Architectural changes in BSs

Measuring Greenness

Green Metrics

- Facility-level Metrics
- Equipment-level Metrics
- Network-level Metrics

Network Planning

Heterogeneous Networks

- Macro-cells
- Micro-cells
- Pico-cells

Green Cellular Network

System Design

Enabling Technologies

- Green Comm. via Cognitive Radio
- Green Comm. via Cooperative Relays
  - Fixed relays
  - User cooperation

Energy Efficiency in Future Generation Wireless Systems

- Low Energy Spectrum Sensing
- Energy-Aware MAC & Green Routing
- Energy-Efficient Resource Management
- Cross-Layer Design & Optimization
- Uncertainty Issues

3. Architecture

- **Minimizing BS energy consumption**
  - Improvements in Power Amplifier
  - Power Saving Protocols
- **Energy-Aware Cooperative BSs**
  - Network self-organizing techniques
  - Cell zooming

Architecture: energy savings in base station

- The number of worldwide cellular BSs has increased from **a few hundred thousands** to many **millions** within a last couple of years.
  - Each BS can increase up to **1,400** watts and energy costs per BS can reach to **$3,200** per annum with a carbon footprint of **11 tons** of CO2.

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Cont.

- BS equipment manufacturers have begun to offer a number of cost friendly solutions to reduce power demands of BSs and to support **off-grid BSs** with **renewable** energy resources.
  - Nokia Siemens Networks Flexi Multiradio Base Station, Huawei Green Base Station and Flexenclosure Esite solutions are examples of such recent efforts.

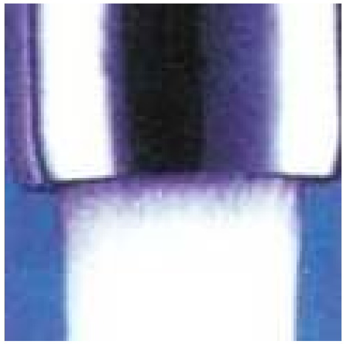
Minimizing BS energy consumption

- The energy consumption of a typical BS can be reduced by improving the **BS hardware design** and by including *additional software* and *system* features to balance between energy consumption and performance.

- Some typical system features to improve BS energy efficiency are to shut down BS during low traffic or cell zooming.

Improvements in power amplifier

- Radio consumes more than 80% of a BS's energy requirement, of which power amplifier (PA) consumes almost 50%.
  - 80-90% of that is wasted as heat in the PA, and which in turn requires air-conditioners, adding even more to the energy costs.
- The **total efficiency** of **a currently deployed amplifier**, which is the ratio of **AC power input** to **generated RF output power**, is generally in anywhere in the range from 5% to 20%.



Power saving protocols

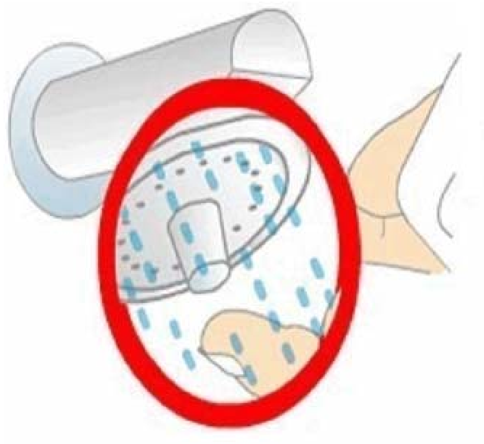
- With the high data requirements, although BSs and mobile units (MU) employing newer hardware (such as **multiple-input and multiple-output** (MIMO) antennas) increase spectral efficiency allowing to transmit more data with the same power
  - Power consumption is still a significant issue for future high speed data networks and they require energy conservation both in the hardware circuitry and protocols.

Power saving protocol in the **mobile handset**

- A fairly intuitive way to save power is to switch off the transceivers whenever there is no need to transmit or receive.
- The LTE standard utilizes this concept by introducing power saving protocols such as **Discontinuous Reception** (DRX) and **Discontinuous Transmission** (DTX) modes for the **mobile handset**.
  - **DRX** and **DTX** are methods to momentarily power down the devices to save power while remaining connected to the network with reduced throughput.
  - The device negotiates with the BS and the BS will not schedule the user for transmission or reception when the radio is off.

Power saving protocol in the BSs ?

- Power saving protocols for BSs have not been considered in the current wireless standards.
  - The traffic per hour in a cell varies considerably over the time and BSs can regularly be under low load conditions, especially during the nighttime.
- In future wireless standards, **energy saving potential of BSs needs to be exploited by designing protocols to enable sleep modes in BSs**.



Energy-aware cooperative BS power management

- During **daytime**, traffic load is generally higher in office areas compared to residential areas, while it is the other way around during the night.
- There will always be some cells under low traffic load, while some others may be under heavy traffic load.
- **A static cell size** deployment is not optimal with fluctuating traffic conditions.
  - For next generation cellular networks based on micro-cells and pico-cells and femtocells, such fluctuations can be very serious.

Cell-Breathing

- While limited cell size adjustment called “**cell-breathing**” currently happens in currently deployed **CDMA** networks
- A cell under heavy traffic load or interference reduces its size through power control and the mobile user is handed off to the neighbouring cells

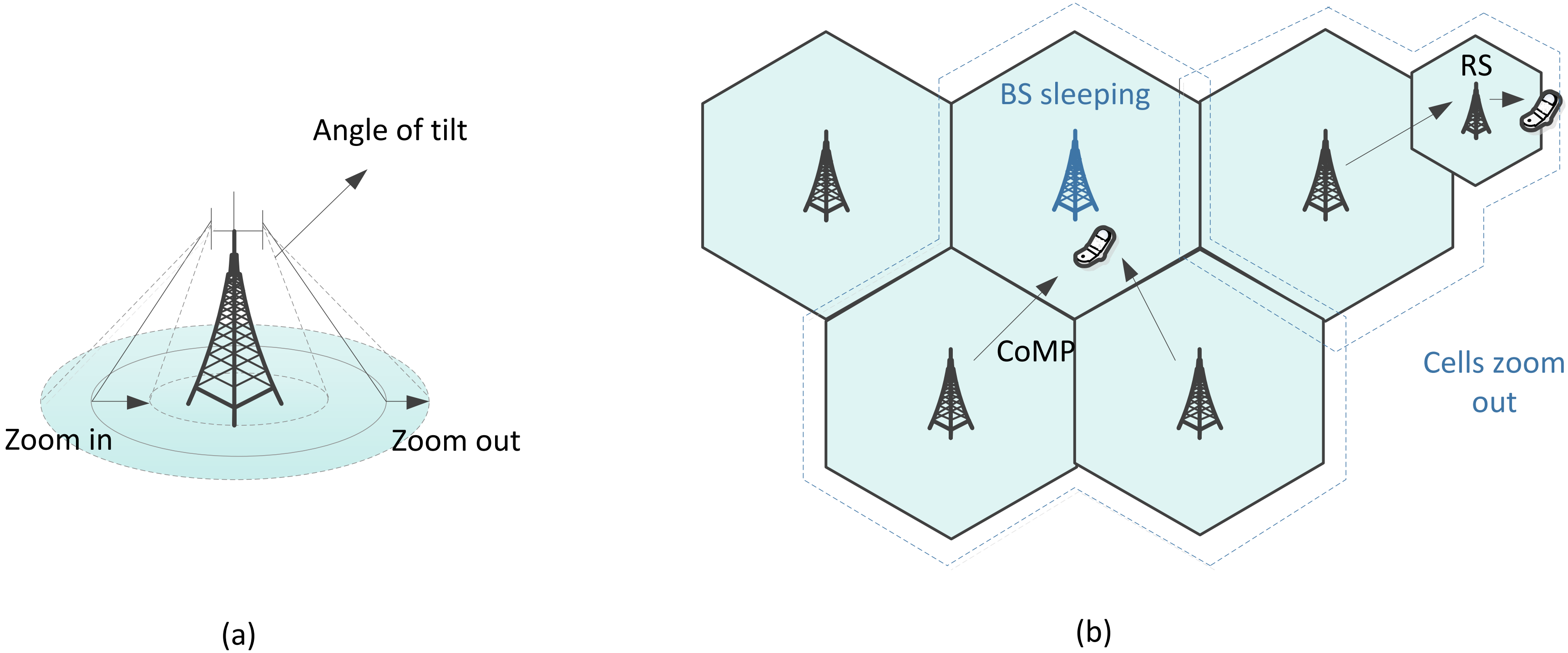
Self-organizing networks (SON)

- Such concepts of **self-organizing networks** (SON) have been introduced in 3GPP standard (3GPP TS 32.521)
  - Add network management and intelligence features so that the network is able to optimize, reconfigure and heal itself in order to reduce costs and improve network performance and flexibility.
- Using the numerical results, the energy savings can be obtained (of the order of 20%, and above) by selectively reducing the number of active cells that are under low load conditions.

Cell Zooming

- Some researchers introduced the notion of **energy partition**s which is the associations among powered-on and powered-off BSs, and use this notion as the basis of rearranging the energy configuration.
- A similar but even more flexible concept called "**Cell Zooming**"
- Cell zooming is a technique through which BSs **can adjust the cell size according to network or traffic situation**, in order to balance the traffic load, while reducing the energy consumption.

Techniques to implement cell zooming



Green Cellular Network

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- **Network Planning**
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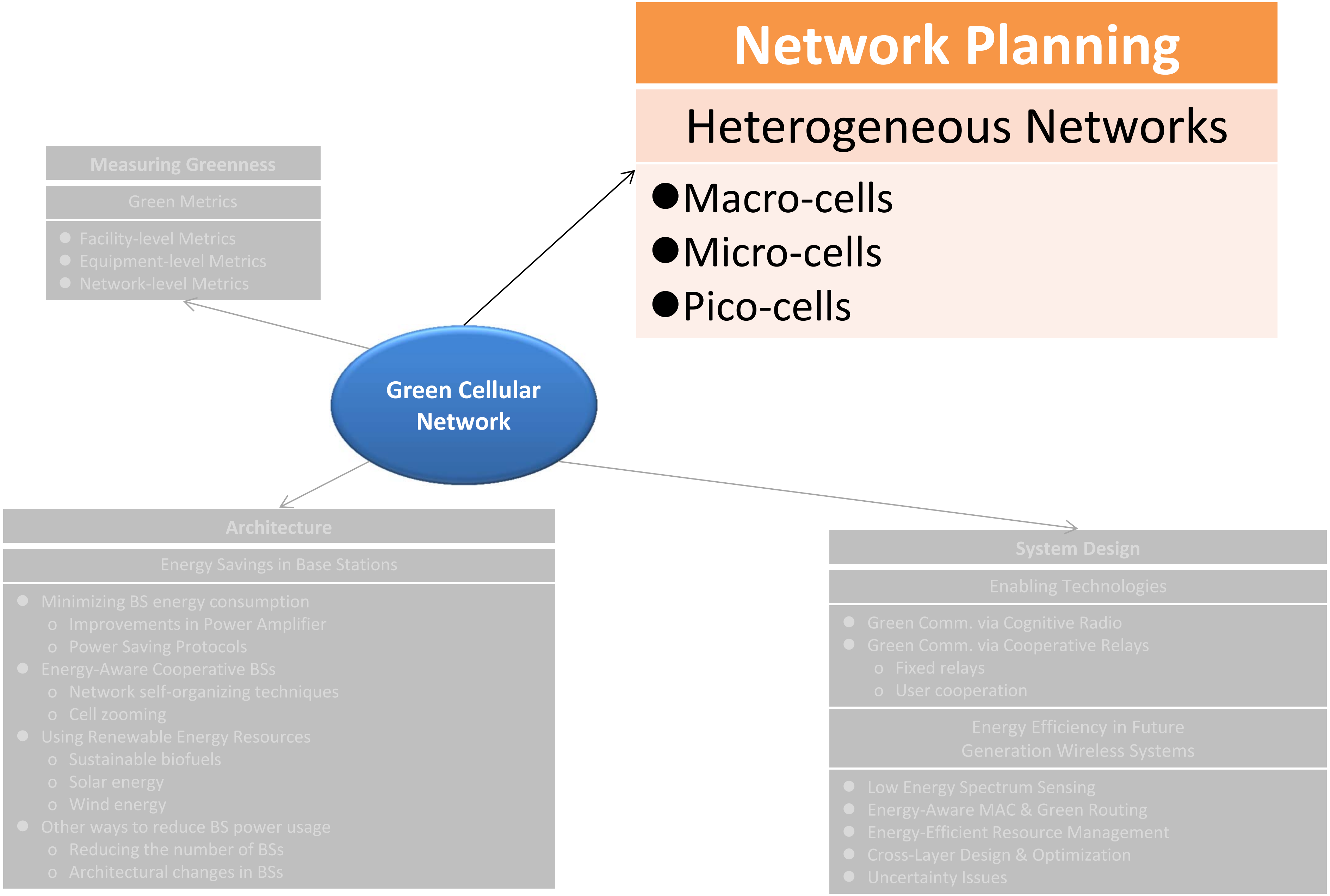
Technical roadmap for Green Cellular Networks: A taxonomy graph



4. Network planning:

- Macro-cells
- Micro-cells
- Pico-cells

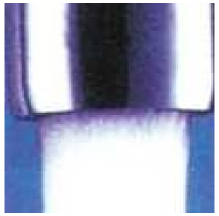
Heterogeneous network deployment

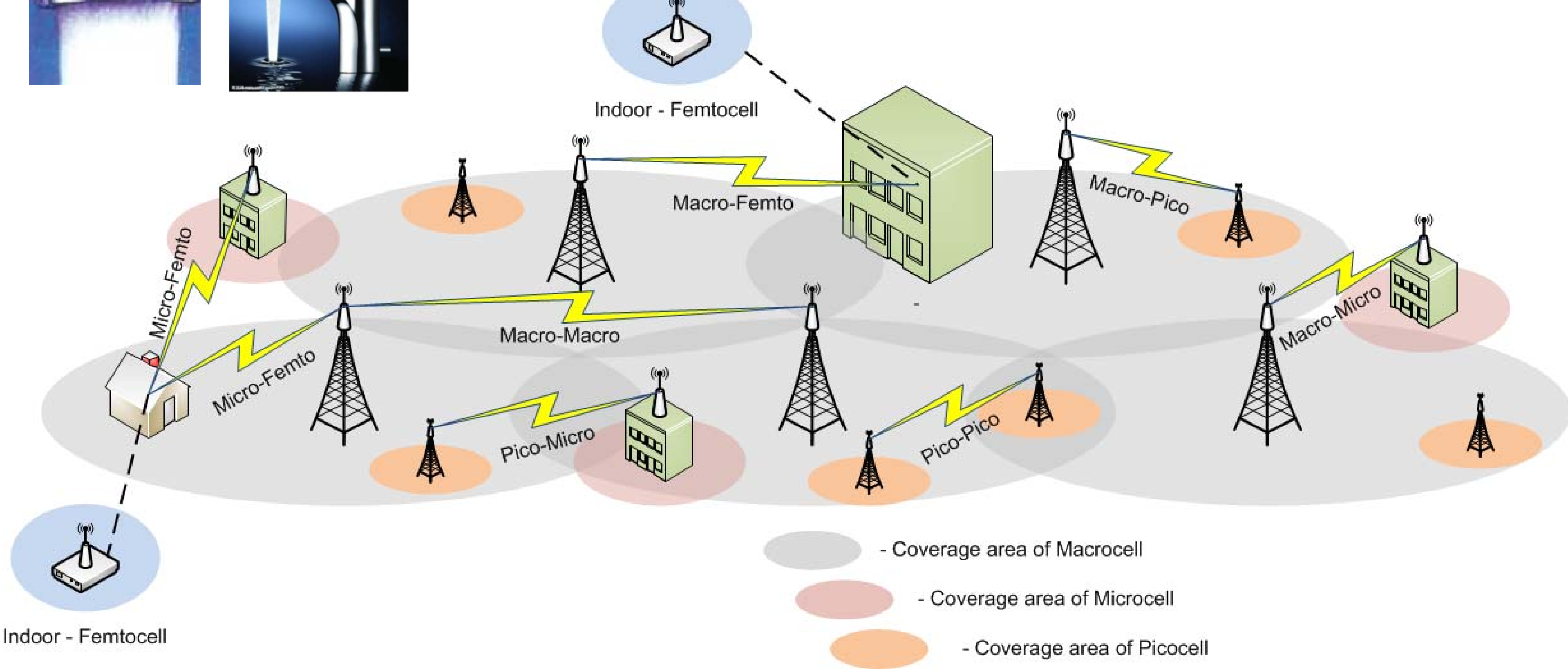
- The exponential growth in demand for higher data rates and other services in wireless networks **requires a more dense deployment of base stations** within network cells.
- The conventional **macro-cellular network** deployments **are less efficient**, it may not economically feasible to modify the current network architectures.
- Macrocells are generally designed to **provide large coverage** and are **not efficient to providing high data rates**.
- One way to make the cellular networks more power efficient in order to sustain high speed data-traffic is **by decreasing the propagation distance** between nodes, hence **reducing the transmission power**.

Small-Cell Networks

- Cellular network deployment solutions based on **smaller cells** such as **micro**, **pico** and **femto-cells** are very promising in this context.
- A typical **heterogeneous network** deployment is shown in the next figure.

Fig . A typical heterogeneous network deployment

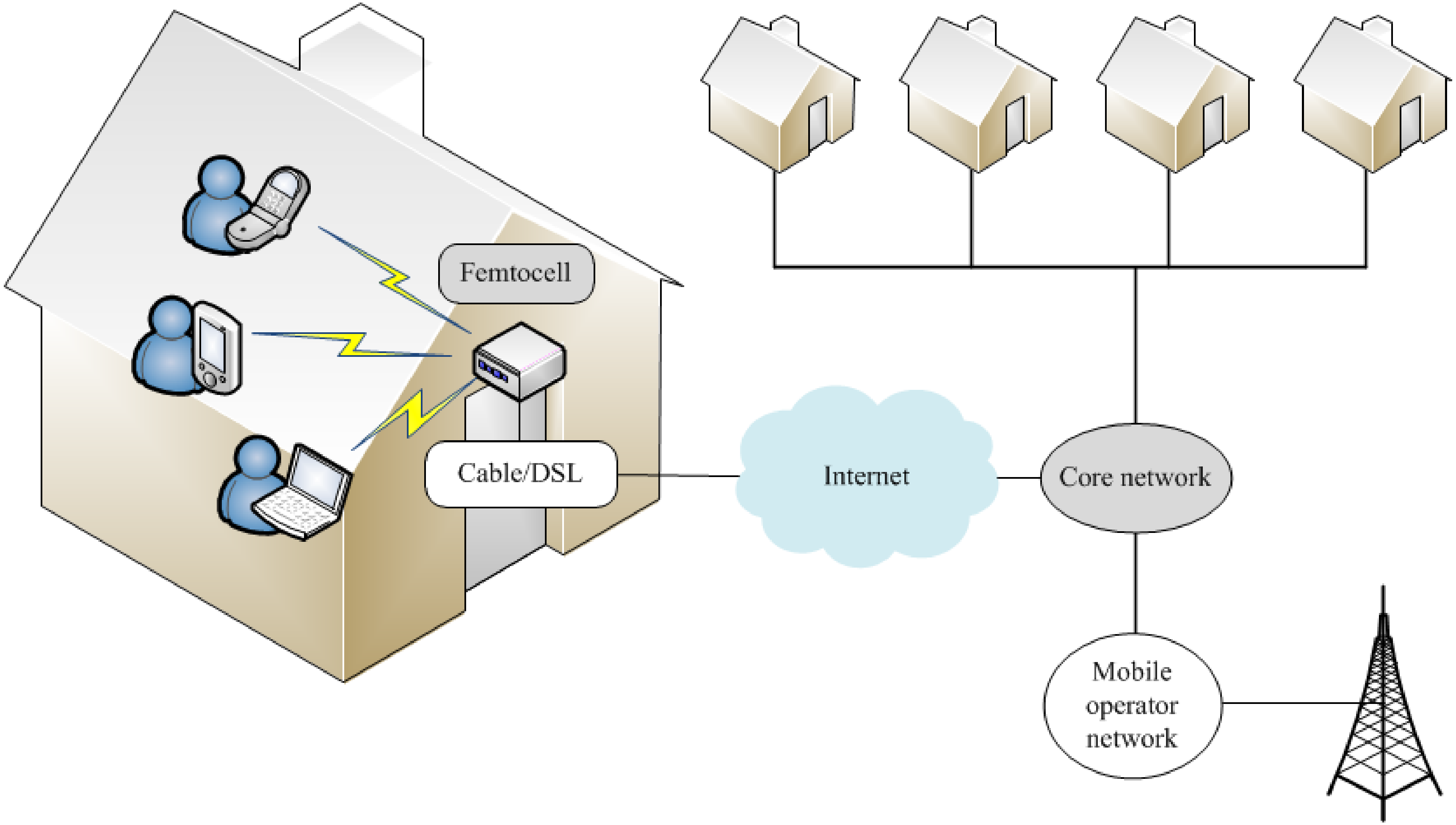




Micro/pico cell

- A micro/pico cell is a cell in a mobile phone network served by **a low power cellular BS** that covers a small area with dense traffic such as a shopping mall, residential areas, a hotel, or a train station.
- A typical range of a micro/pico cell is in the order of few hundred metres.
- Femtocells are designed to serve much smaller areas such as private homes or indoor areas.
- The range of femtocells is typically only a few, metres and they are generally wired to a private owners' cable broadband connection or a home digital subscriber line (DSL).

Femtocell



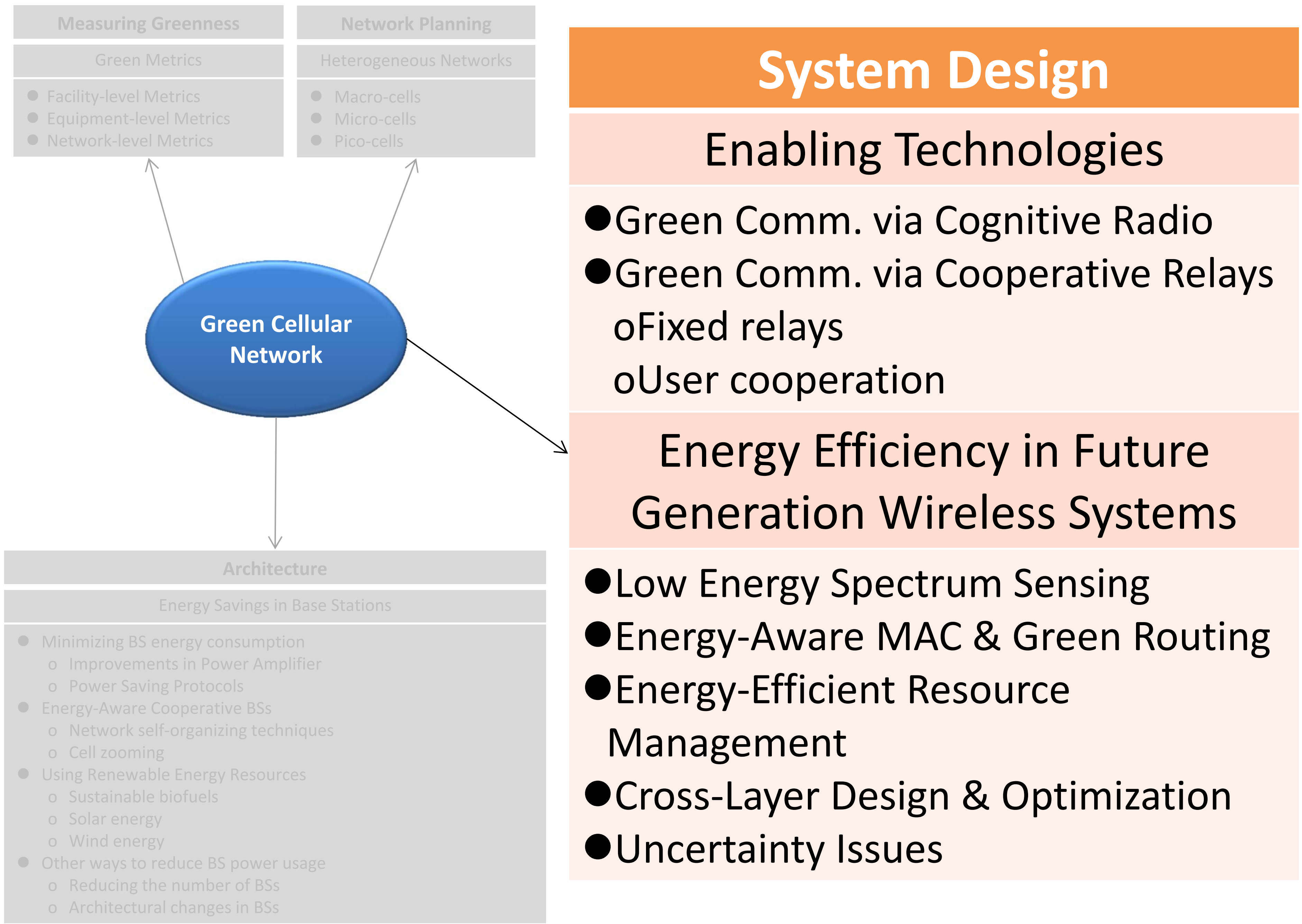
Femtocell
Cable/DSL
Internet
Core network
Mobile operator network

Cont.

- **Smaller cells because of their size are much more power efficient** in providing broadband coverage.
- A typical femtocell might only have a 100mW PA, and draw 5W total compared to a 5KW that would be needed to support macrocell.
- A jointly macrocell/picocell network can reduce the energy consumption of the network by up to 60% compared to a network with macro-cells only.

- Measuring Greenness
- Architecture
- Network Planning
- **System Design**

Technical roadmap for Green Cellular Networks: A taxonomy graph



5. System Design

- **Enabling Technologies**
  - Green Comm. via Cooperative Relays
    - Fixed relays
    - User cooperation
  - Green Comm. via Cognitive Radio
- **Energy Efficiency in Future**
  - Generation Wireless Systems
  - Low Energy Spectrum Sensing
  - Energy-Aware MAC & Green Routing
  - Energy-Efficient Resource Management
  - Cross-Layer Design & Optimization
  - Uncertainty Issues

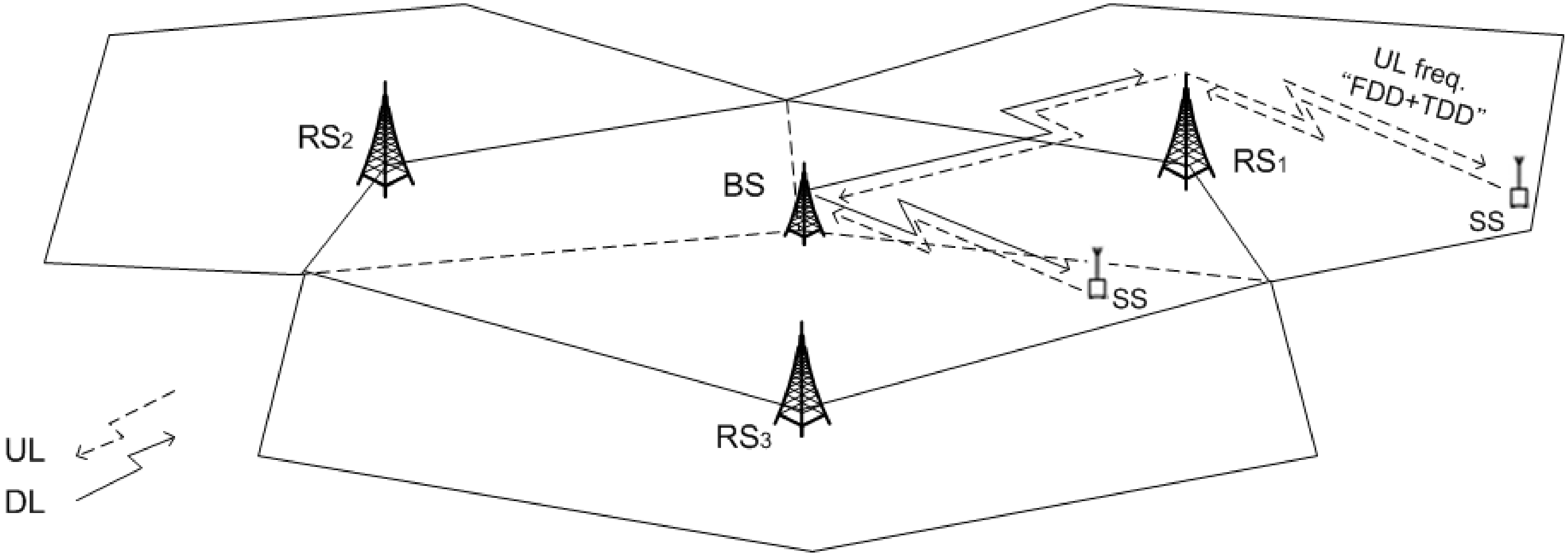
Cooperative Relays to deliver green communication

- Enabling green communication via **fixed** relays
- Green communications
  in cellular networks via **user cooperation**

Enabling green communication via **fixed** relays

- Installing new BSs in order to have a higher BS density can be **very expensive**.
- We can install **relays** instead of new BSs, which is economically advantageous, and does not introduce much complexity to the network.
  - Relays need not be as high as BSs, because they are supposed to cover a smaller area with a lower power.
  - Relays can be wirelessly connected to a BS, instead of being attached to the backhaul of the network by wire using a complicated interface.

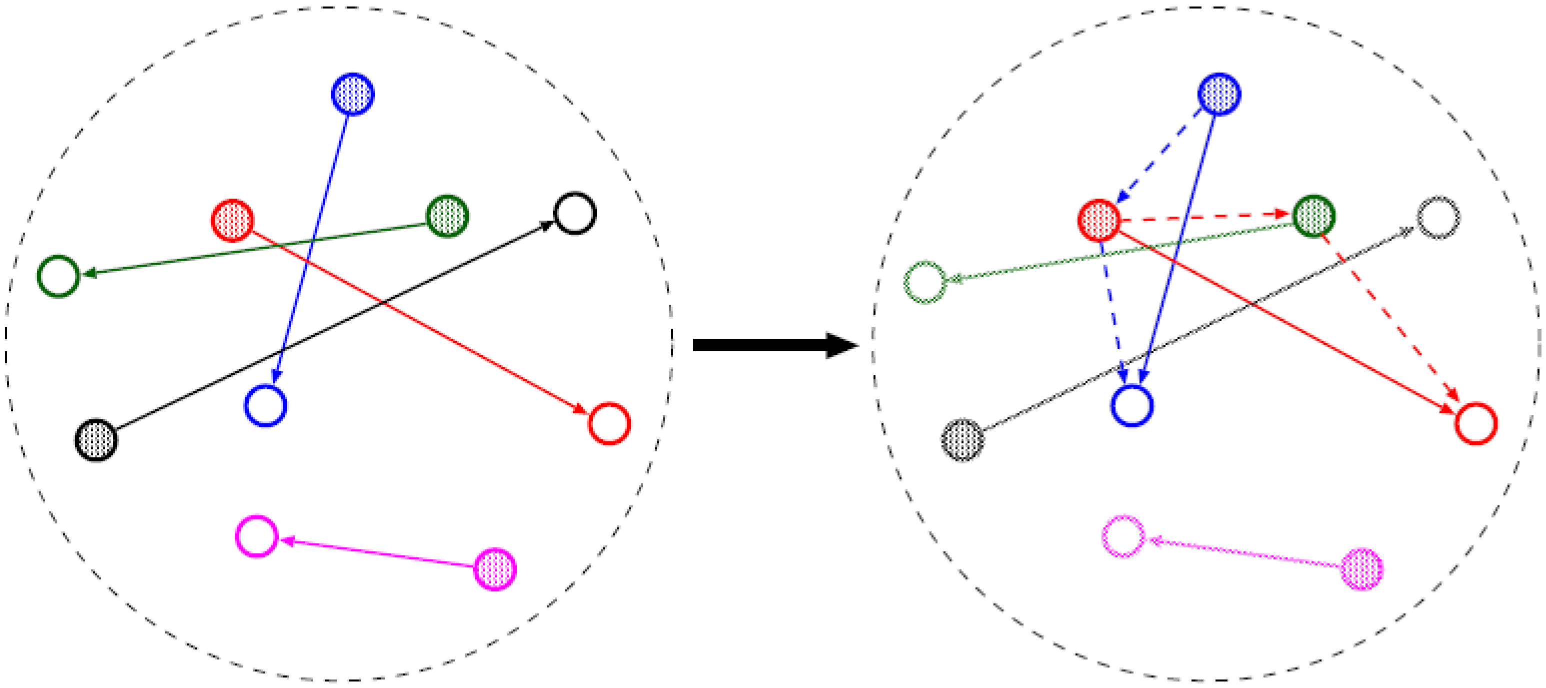
BS, RS, and respective “hexagonal” coverage areas.



Green communications in cellular networks via **user cooperation**

- **User cooperation** was first introduced, and has been shown that not only it **increases the data rate**, but also the system is **more robust**.
- **Energy efficiency** issues of user cooperation render this paradigm unappealing in wireless mobile networks.
- **Increased rate** of one user **comes at the price of the energy consumed by another user** acting as a relay.
- The limited battery life time of mobile users in a mobile network leads to **selfish users** who do not have incentive to cooperate.

Partner selection and cooperation



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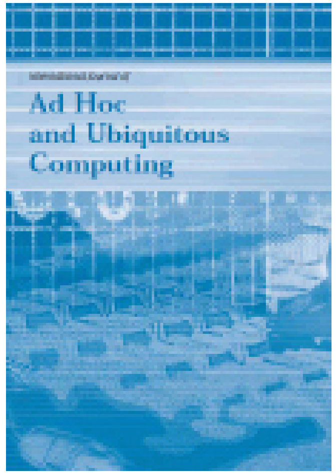
- In a very recent work by Nokleby and Aazhang, this fundamental question has been posed: **whether or not user cooperation is advantageous from the perspective of energy efficiency**.
  - A game-theoretic approach is proposed to give **users** incentive to act as **relays** when they are idle, and it is shown that user cooperation has the potential of simultaneously improving both user's bits-perenergy efficiency under different channel conditions.

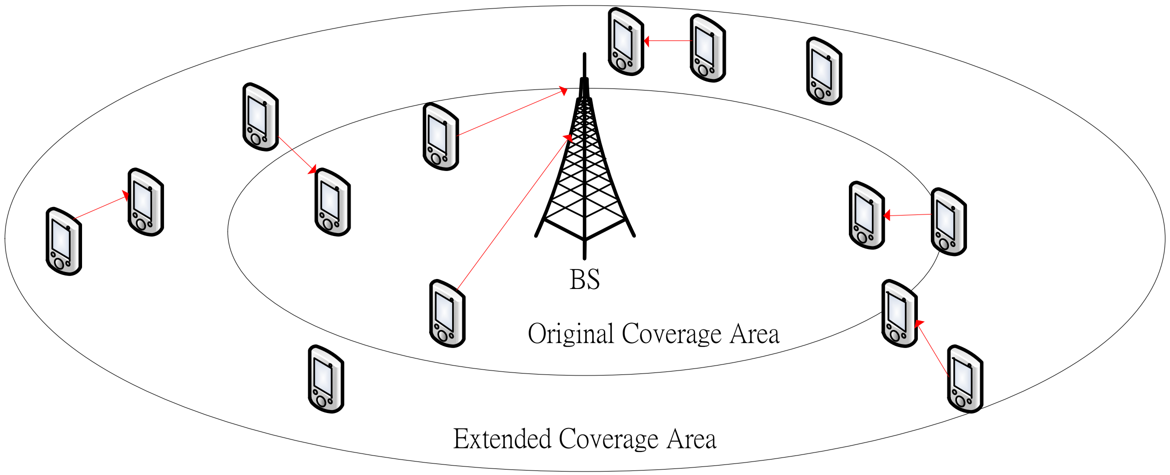
- **User cooperation** in which **selfish users** find cooperation favourable to their energy concerns, has recently been considered, but still is an open question.

Adaptive technologies for hybrid ad-hoc/cellular network architecture (Ahmed Barnawi**)**

- International Journal of Ad Hoc and Ubiquitous Computing, 2011.

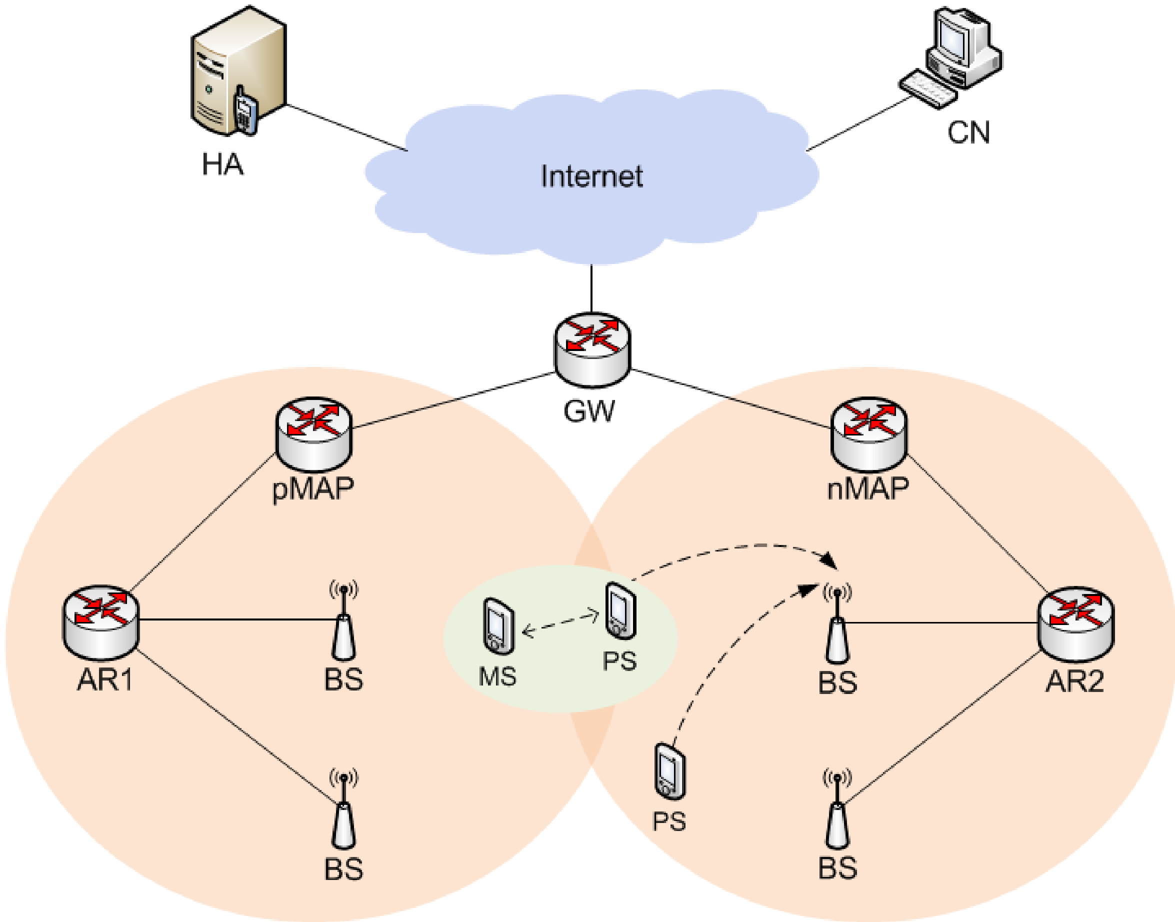


- Barnawi, A. and Gardiner, J. (2009) *Method and Apparatus for Supporting Ad-Hoc Networking Over UMTS Protocol, patent,* **United States Patent** Application 20090040985, 12/02/2009.



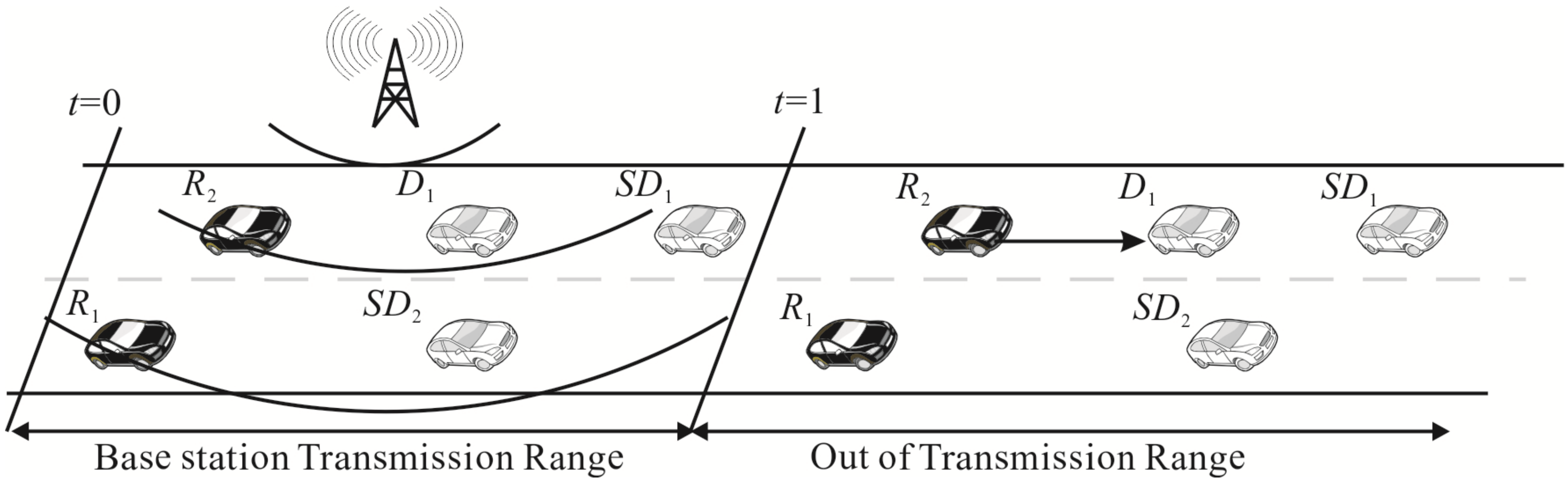
Our Result: A Cross-Layer Partner-Assisted Handoff Scheme in IEEE 802.16e

- Wireless Communication and Mobile Computing, Vol. 11, Issue 4, pp. 522-541, April 2011. (Yuh-Shyan Chen *et al*.)



VC-MAC: A Cooperative MAC Protocol in Vehicular Networks

- IEEE Transactions on Vehicular Technology, vol. 58, no. 3, pp. 1561–1571, 2009.

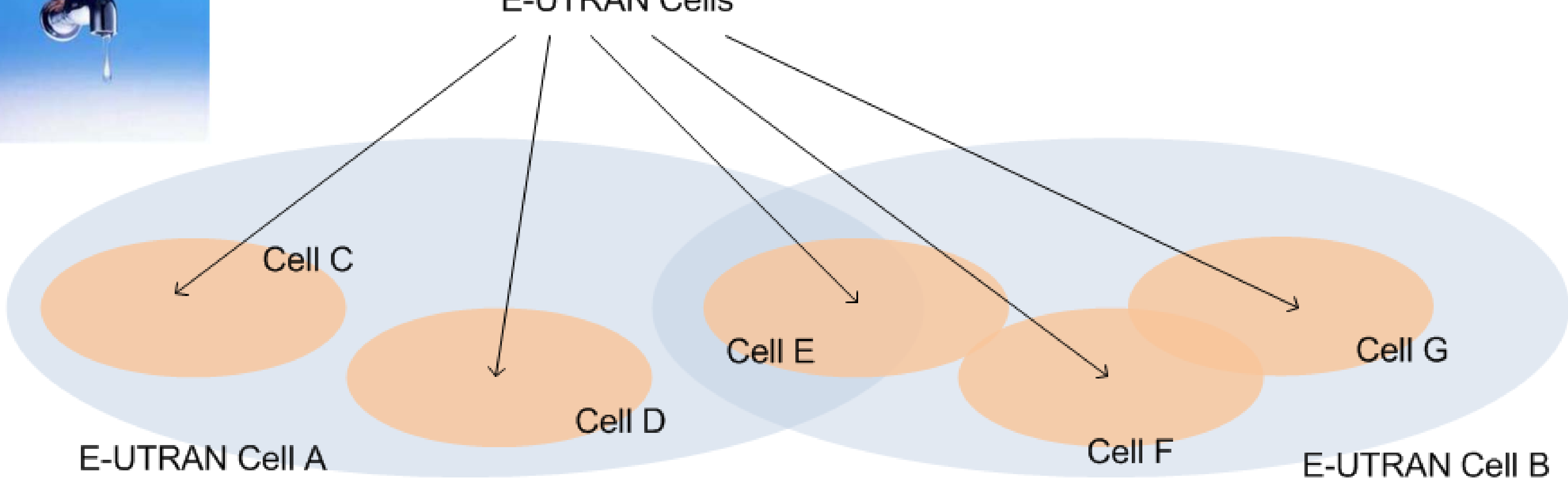


Energy Saving for E-UTRAN (3GPP LTE)

- The 3GPP TS 36.927 (release 10) defines potential solutions for **energy saving for E-UTRAN**
- Indicates that the cell can be totally switched off during the energy saving (ES) procedure.
- The ES procedure may be triggered in case of the light traffic or no traffic.
  - Since there are thousands of femtocells within a macrocell area, the femtocell deployments may increase energy consumption except for the case of low femtocell/user densities and the use of femtocells with "idle" mode.

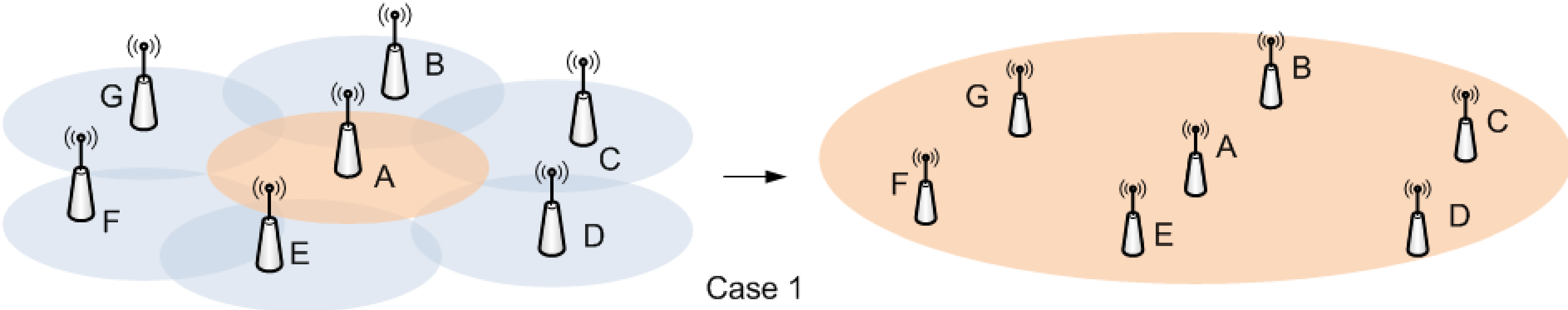
Inter-eNB scenario 1

In general, inter-eNB energy saving mechanisms should preserve the basic coverage in the network.



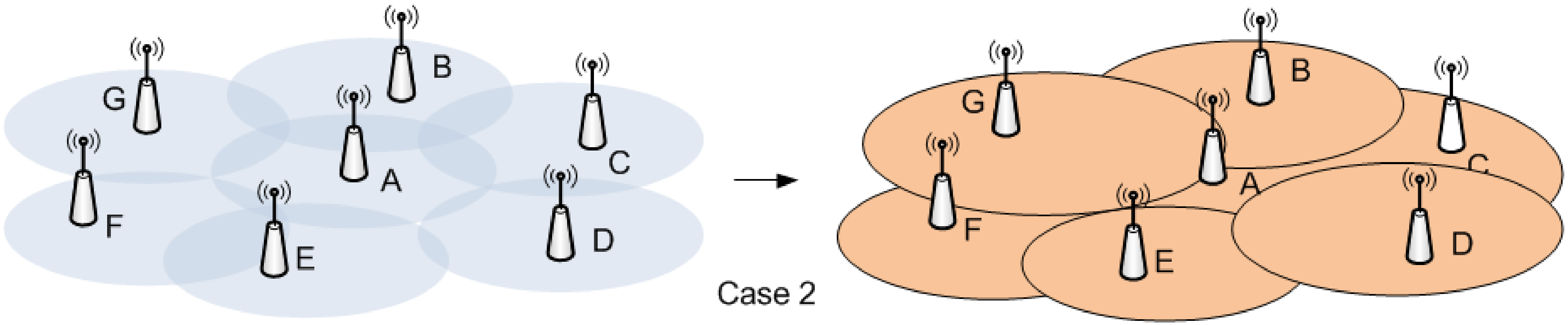
E-UTRAN Cell C, D, E, F and G are covered by the E-UTRAN Cell A and B. Here, Cell A and B have been deployed to provide basic coverage, while the other E-UTRAN cells boost the capacity. When some cells providing additional capacity are no longer needed, they may be **switched off** for **energy optimization**. Both the continuity of LTE coverage and service QoS is guaranteed.

Inter-eNB scenario 2: **Case 1**



At **off-peak** time, energy saving cells may enter dormant mode, while the basic coverage is provided by **one cell** (case 1)

Inter-eNB scenario 2: **Case 2**

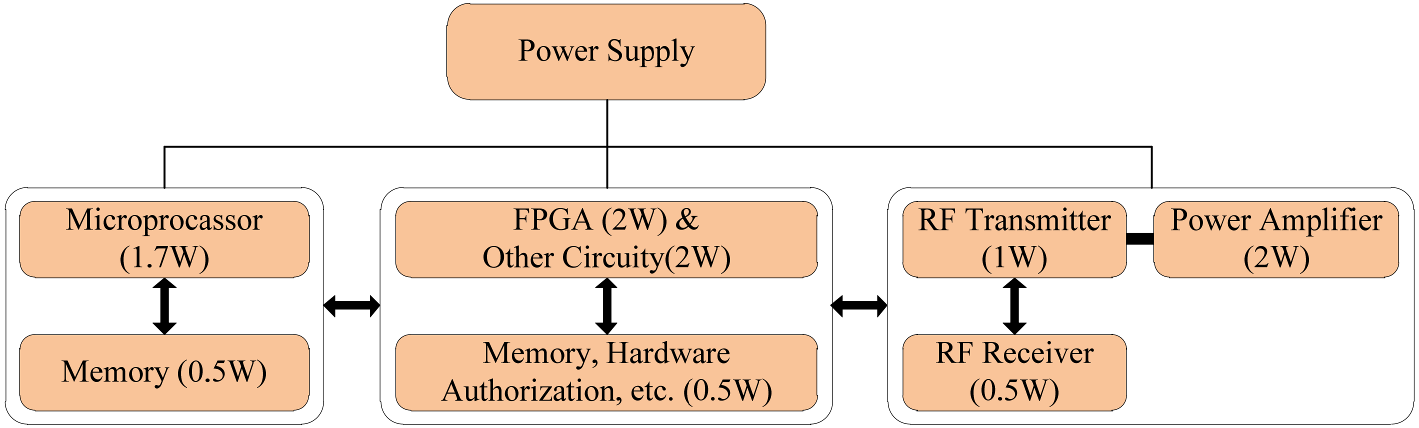


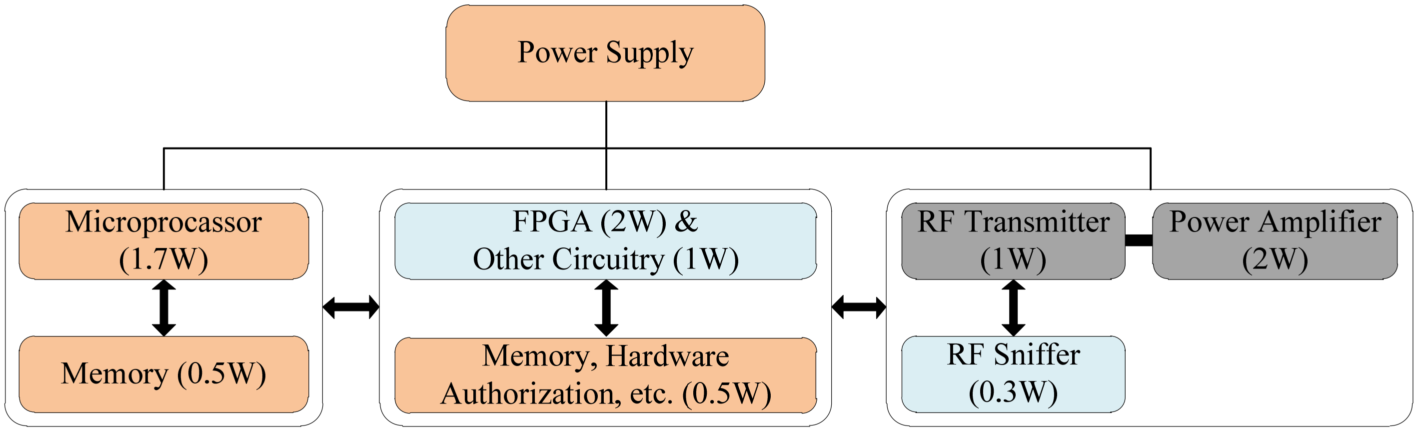
At **off-peak** time, energy saving cells may enter dormant mode, while the basic coverage is provided by **several compensation cells** (case 2).

■Power Saving in Large-Scale Femto-Cell Deployment

- According to the prediction of ABI Research, **more than 36 million femtocells** are expectedly deployed around the world by the end of 2012.
- As **large-scale femto-cell deployment** can result in significant energy consumption, an energy saving procedure that allows femtocell BS to completely turn off its transmissions and processing when not involved in an active call.
  - Depending on the voice traffic model, this mechanism can provide an average power saving of 37.5% and for a high traffic scenario, it can achieve five times reduction in the occurrence of mobility events, compared to a fixed pilot transmission.

Femtocell hardware





Ref: Improving Energy Efficiency of Femtocell Base Stations via User Activity Detection (IEEE WCNC 2010)

Two-tier macrocell-femtocell networks

- A hierarchical radio access network which is a two-tier macrocell/femtocell network. The macrocell base station refers to MBS and the femtocell base station refers to FBS in the two-tier cellular networks.

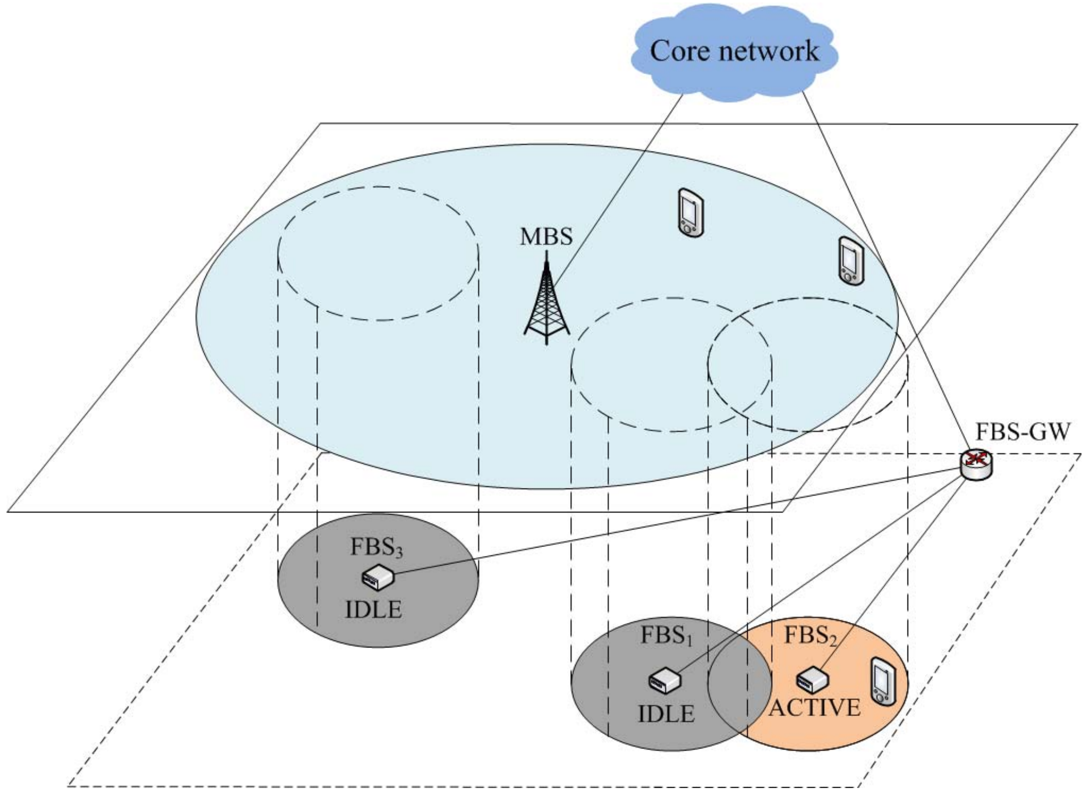
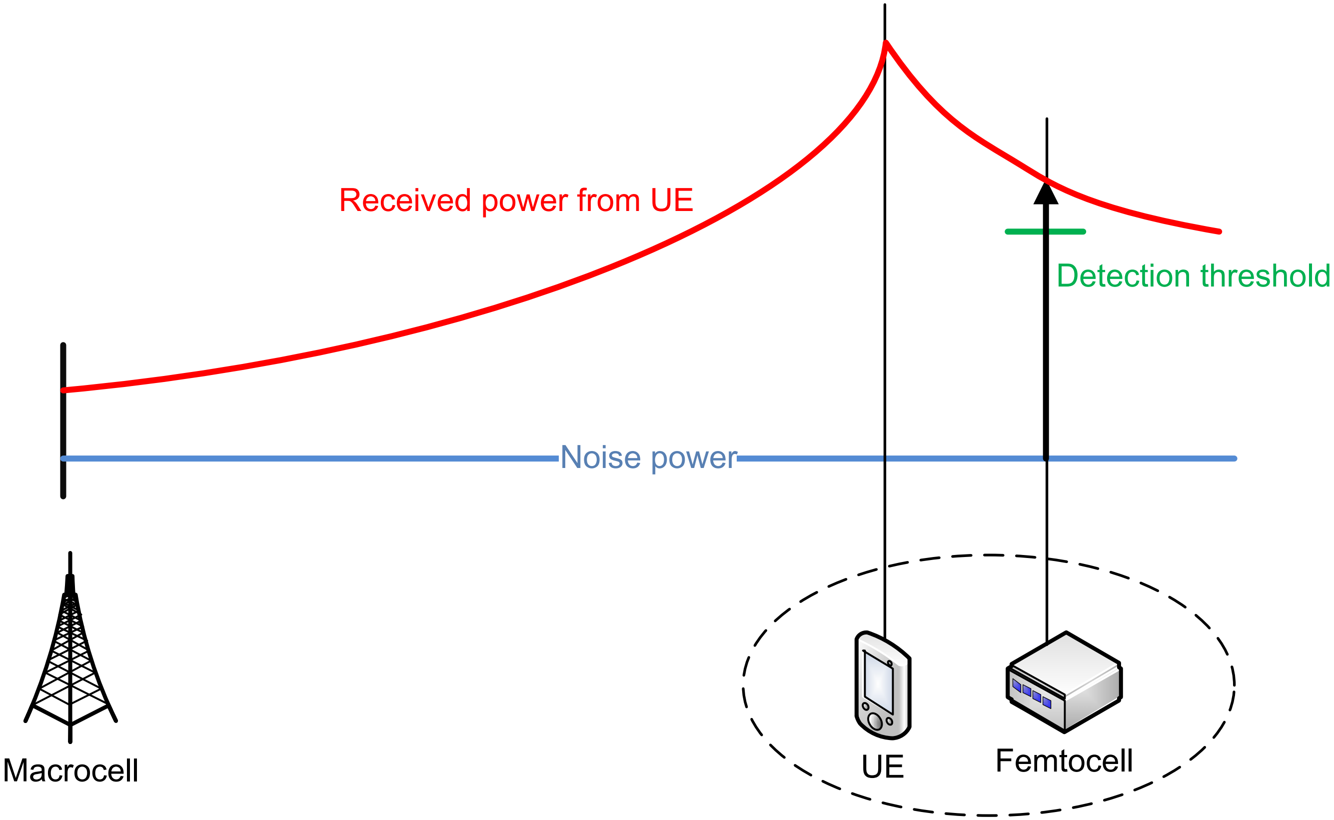
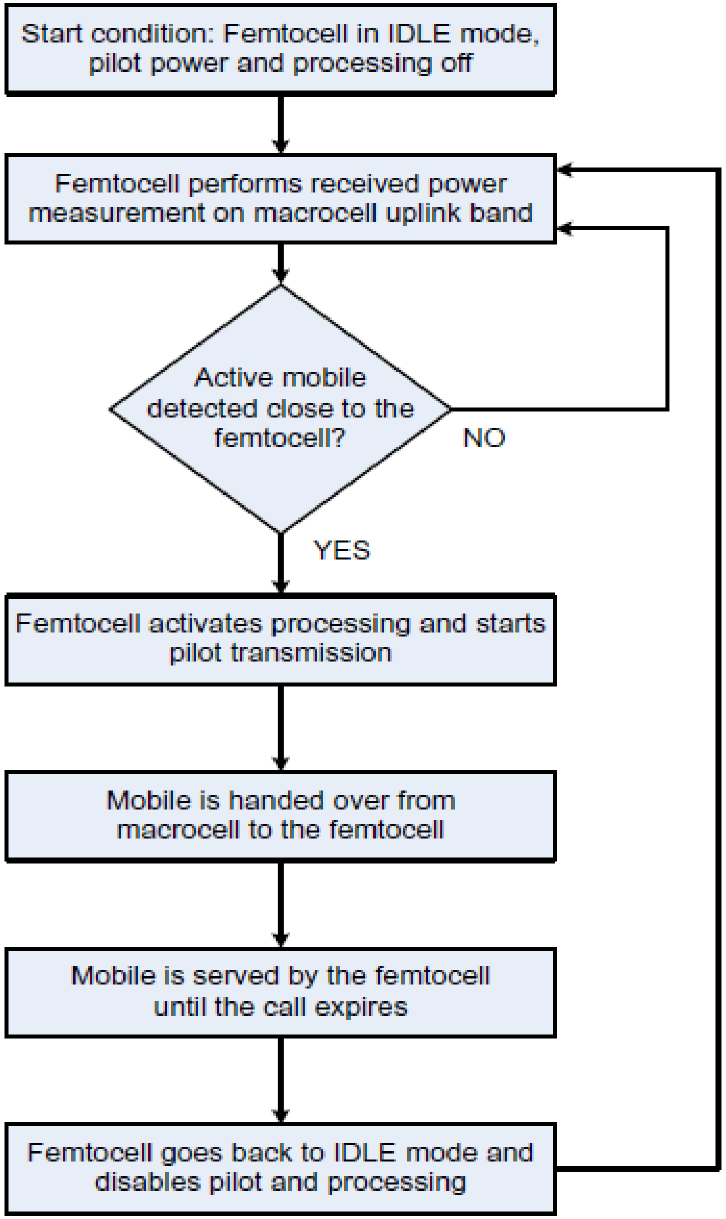


Illustration of noise rise measured at the femtocell

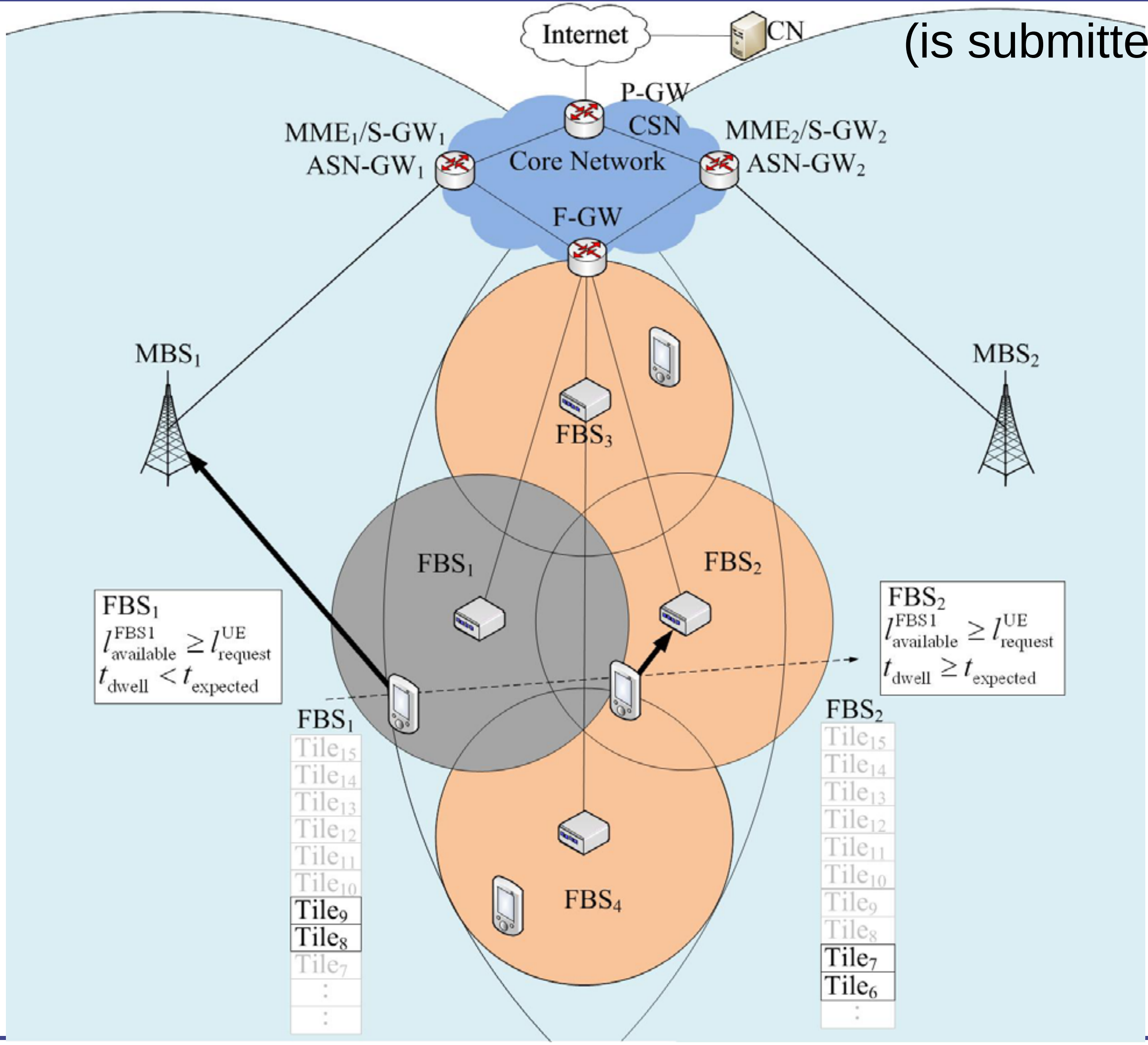


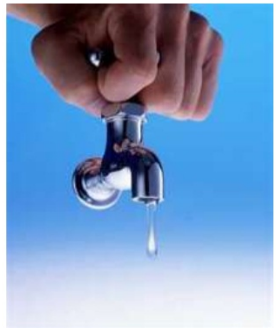
Flowchart of the IDLE mode procedure

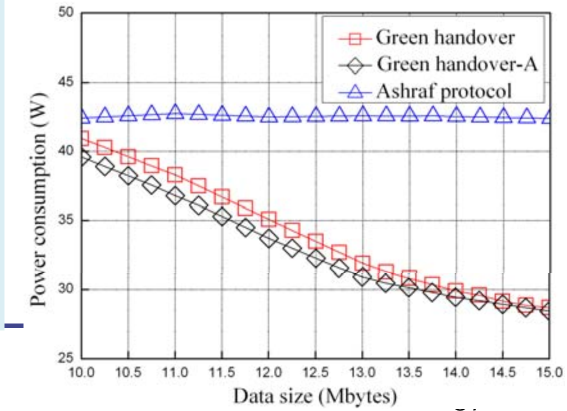


Our Result: A Green Handover Protocol in Two-Tier OFDMA Macrocell-Femtocell Networks

(is submitted to IEEE WCNC 2012)



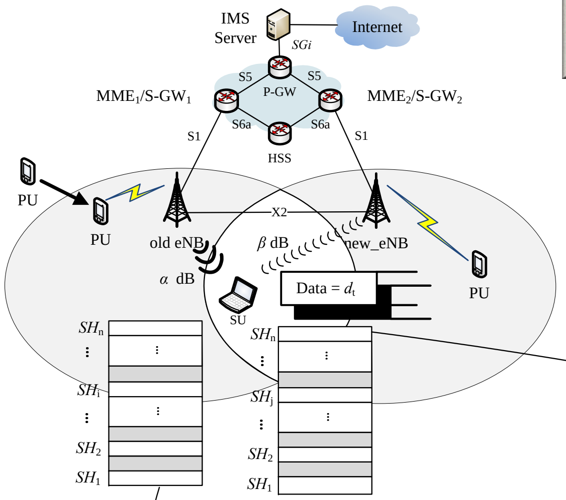


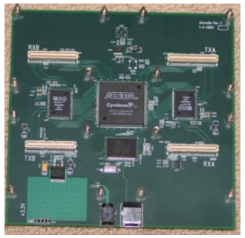


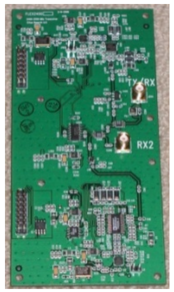
Green communication via **cognitive radio**

- Bandwidth efficiency has been always a crucial concern for wireless communication engineers, and there exist a rich literature on this matter, resulting in **bandwidth efficient systems**, but not always considering power efficiency.
- It has been realized that the allocated spectrum is highly underutilized, and this is where Cognitive Radio comes into the picture.
  - The main purpose of Cognitive Radio is to collect information on the spectrum usage and to **try to access the unused frequency bands intelligently**, in order to compensate for this spectrum underutilization.

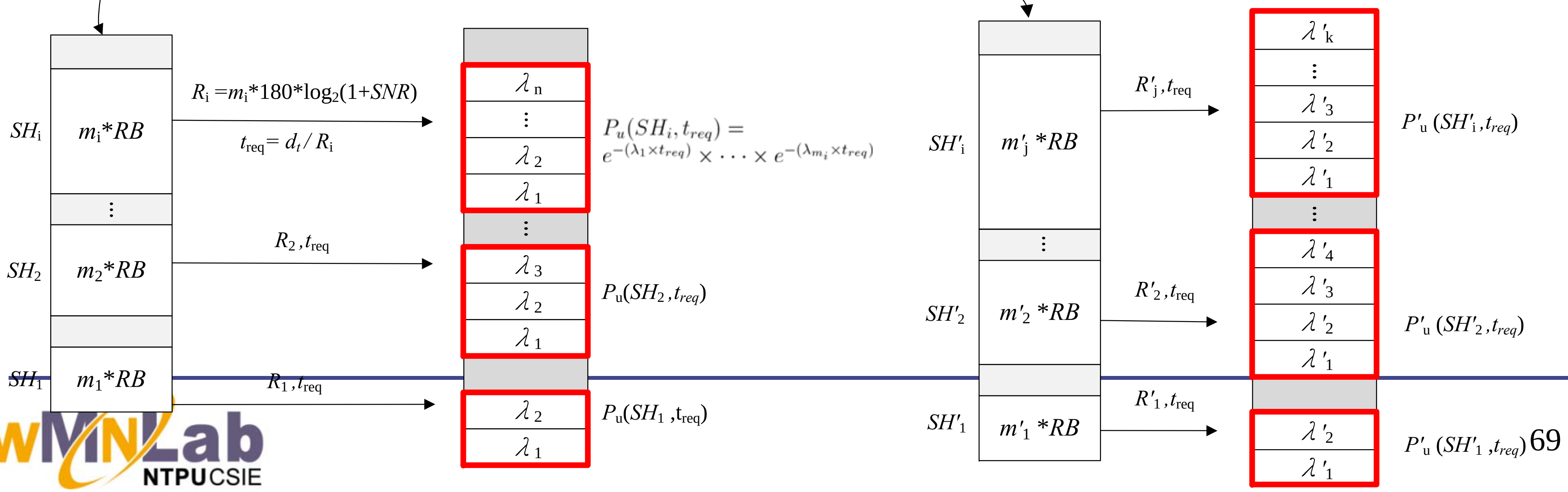
Our Result: A Cross-Layer Protocol of Spectrum Mobility and Handover in Cognitive LTE Networks







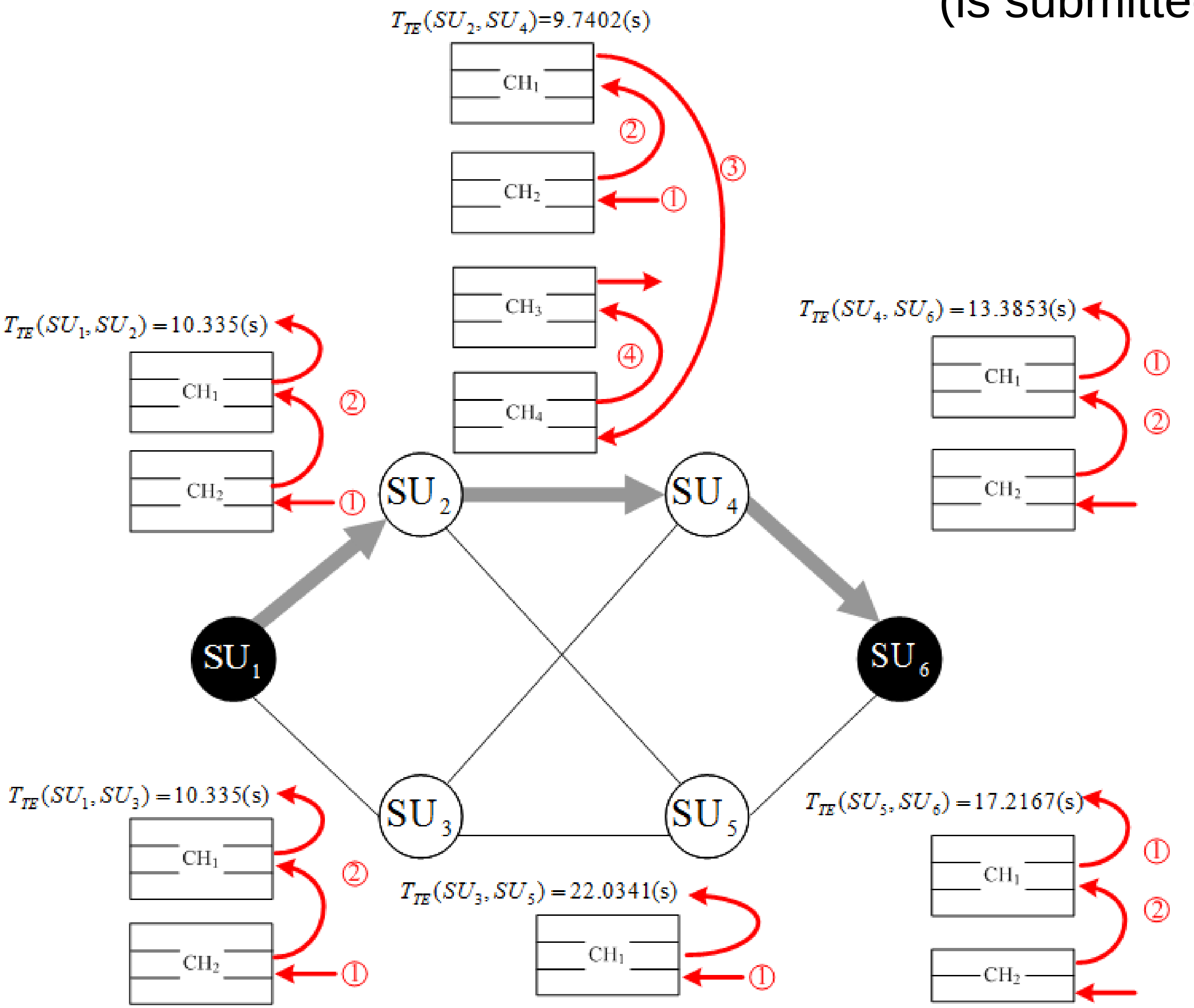
Published at Simulation Modelling Practice and Theory, 2011.

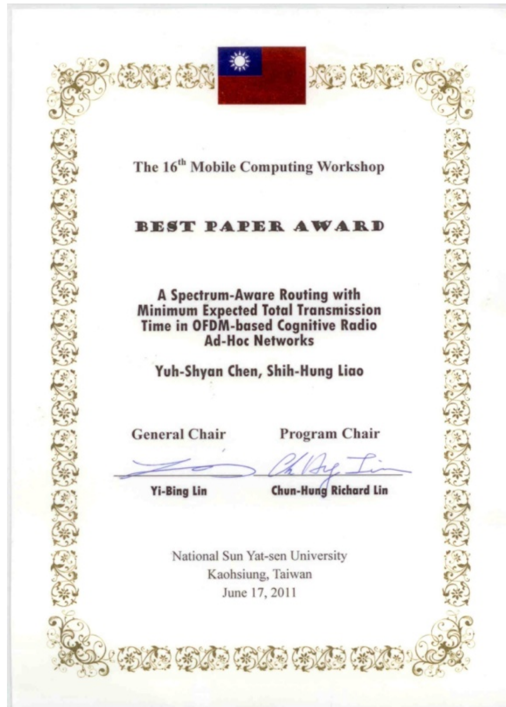


wMNLab NTPU CSIE

Our Result: A Spectrum-Aware Routing in DOFDM-Based Cognitive Radio Ad-Hoc Networks

(is submitted to IEEE WCNC 2012)





How CR can reduce power consumption ?

- The question is why using spectrum more efficiently is important and **how it can reduce power consumption** ?
  - The answer lies under Shannon's capacity formula, where we can see the trade-off between the **bandwidth** and **power**.
  - The capacity increases linearly with bandwidth, but only logarithmically with power.

THEOREM 2: *Let P be the average transmitter power, and suppose the noise is white thermal noise of power N in the band W. By sufficiently complicated encoding systems it is possible to transmit binary digits at a rate*

$$C = W \log_2 \frac{P + N}{N} \qquad (19)$$

with as small a frequency of errors as desired. It is not possible by any encoding method to send at a higher rate and have an arbitrarily low frequency of errors.

- To **reduce power**, we should seek for more bandwidth
- Manage the spectrum optimally and dynamically
  - This falls into the scope of Cognitive Radio.

Cont.

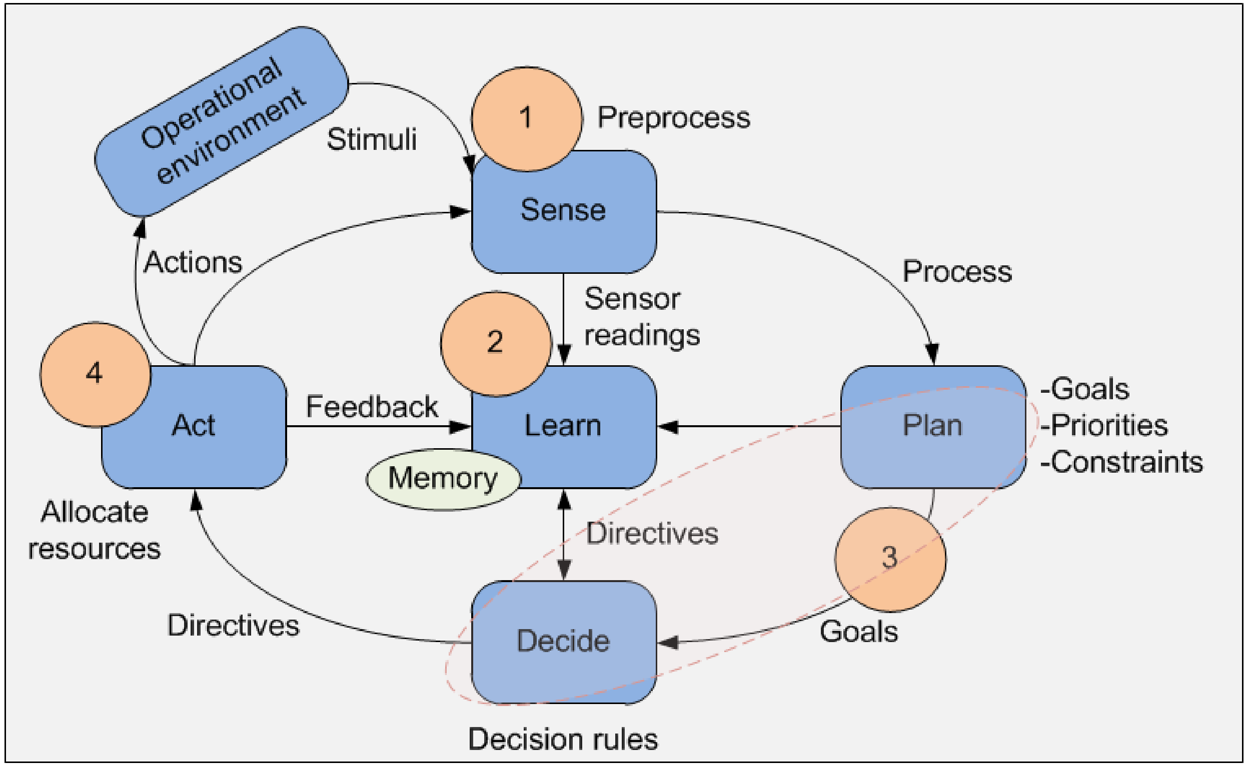
- Up to 50% of power can be saved
  - if the operator dynamically manages its spectrum by activities such as dynamically moving users into particularly active bands from other bands,
  - or the sharing of spectrum to allow channel bandwidths to be increased.
- Efficient spectrum usage is not the only concern of **Cognitive Radio**.
  - In the original definition of Cognitive Radio by J. Mitola, every possible parameter measurable by a **wireless node** or **network** is taken into account (Cognition) so that the network intelligently modifies its functionality (Reconfigurability) to meet a certain objective.

Cont.

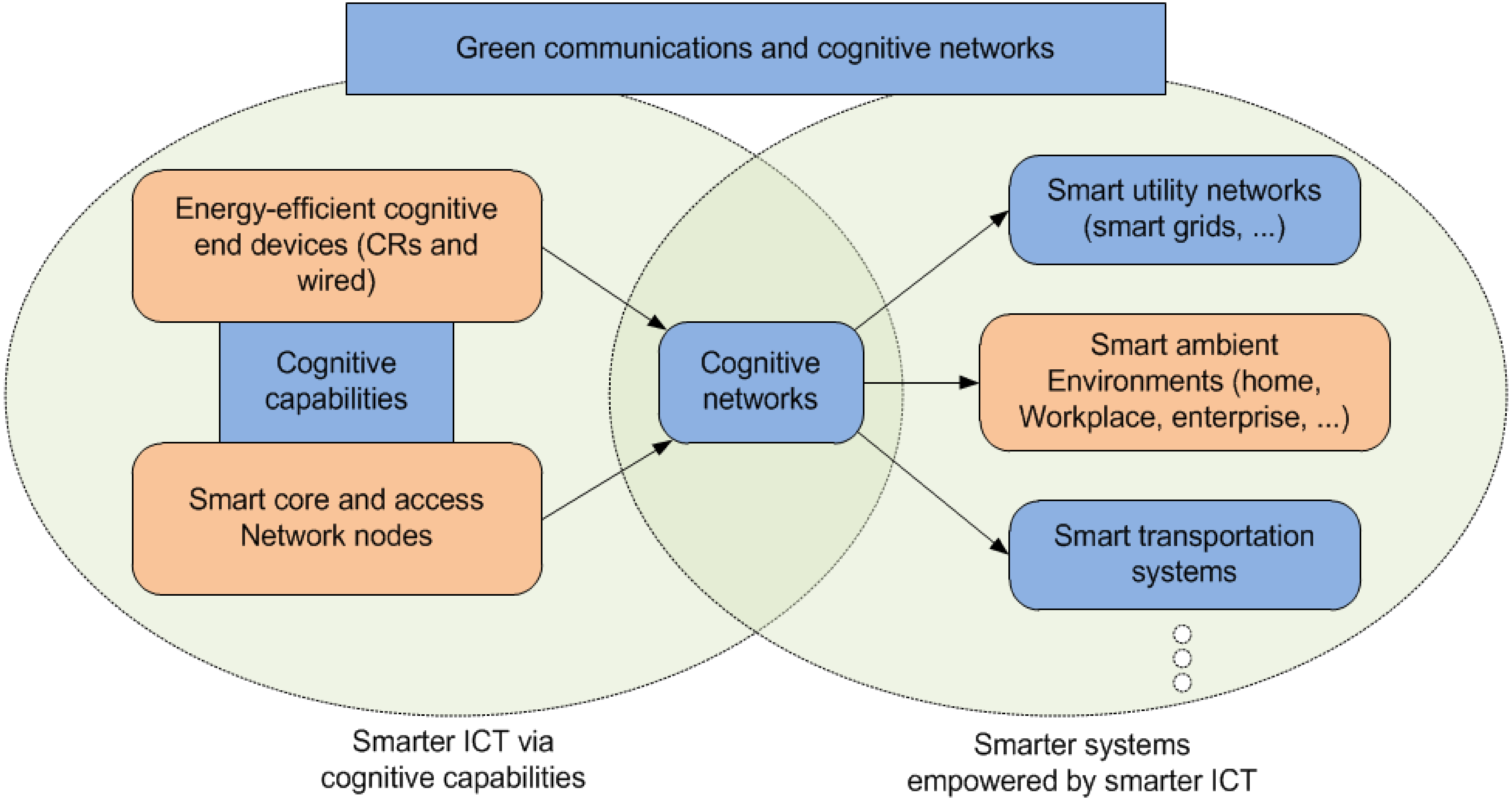
  - One of these objectives can be **power saving**. It has been shown in recent works that structures and techniques based on cognitive radio reduce the energy consumption, while maintaining the required quality-of-service (QoS), under various channel conditions.
- Due to the **complexity** of these proposed algorithms, still vendors find it unappealing to implement these techniques.
- A **roadway** to future would be striving for more feasible, less complex, and less expensive schemes within the scope of Cognitive Radio.

Benefits of Cognitive Radios for Green Wireless Communications

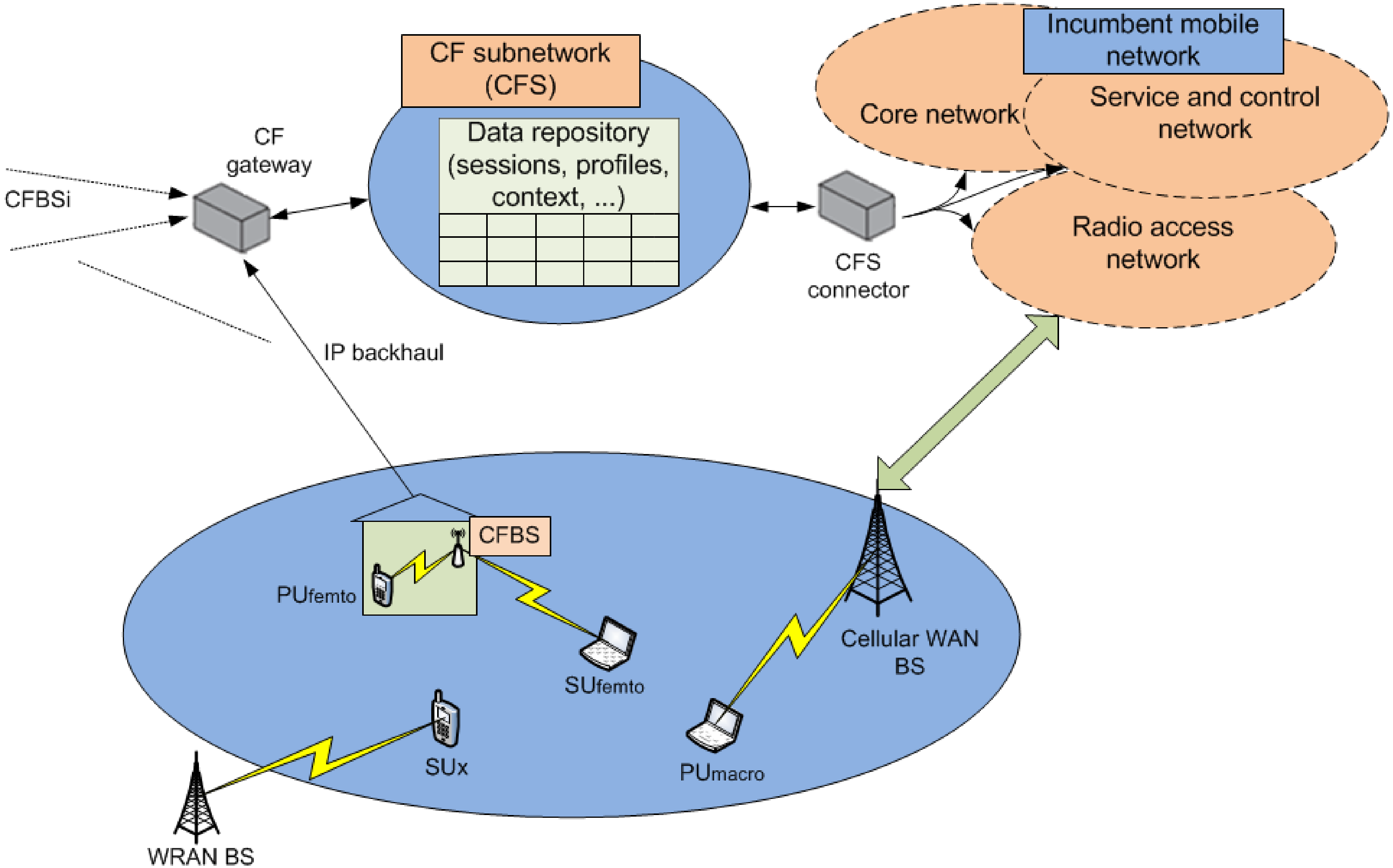
- According to the FCC (FCC NPRM, Dec 17, 2003, ET-03-108), "***A cognitive radio is a radio that can change its transmitter parameters based on interaction with the environment in which it operates***."



To consume only when necessary” (spectrum, energy, hardware)



Cognitive femtocell network



Low-energy spectrum sensing

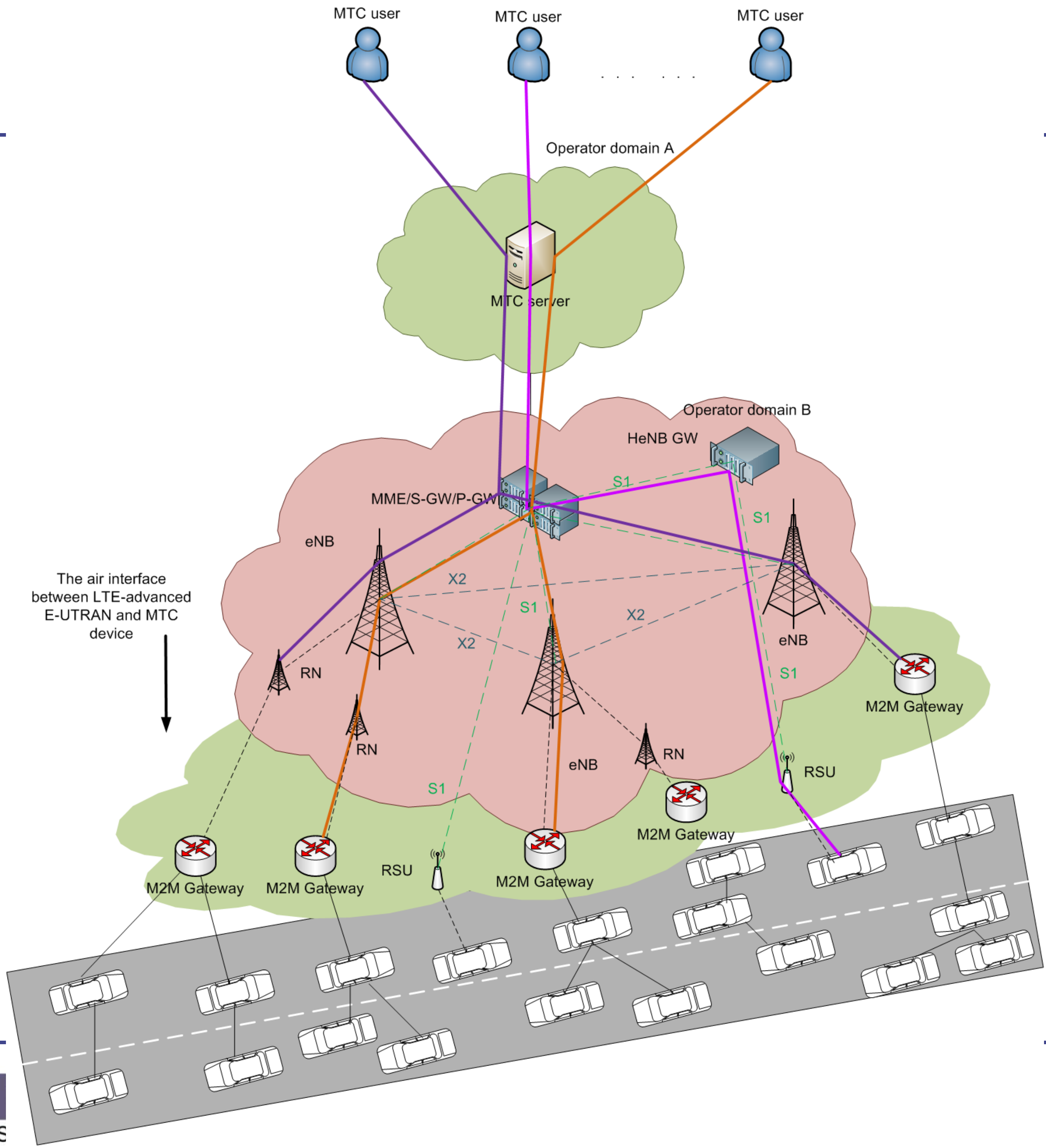
- The use of cognitive radio technology requires frequent sensing of the radio spectrum and processing of the sensor data which would require additional power.
  - They are highly complex and need significant processing power. Therefore, design of **low-complexity** cyclostationary detectors needs to be investigated.
  - **Cooperative spectrum sensing** improves the sensing performance by using the spatial diversity between various sensors.
  - Cooperative sensing would also increase the signaling overhead and thus, energy consumption.
  - By taking into consideration the power consumed for sensing, processing and transmitting sensing data, we need to find conditions under which cooperative sensing is more energy efficient in order to achieve a certain sensing performance.

Energy-aware medium access control

- Medium access control (MAC) in **cooperative** and **cognitive** wireless systems introduces a number of new challenges unseen in traditional wireless systems.
- Coordinating medium access in presence of **multiple relays** with different channel qualities requires a much more agile and adaptive MAC in cooperative systems.
- In **cognitive radio** systems, sensing accuracy, duration and time varying availability of primary user channels are some of the factors affecting the MAC design.

■Green routing

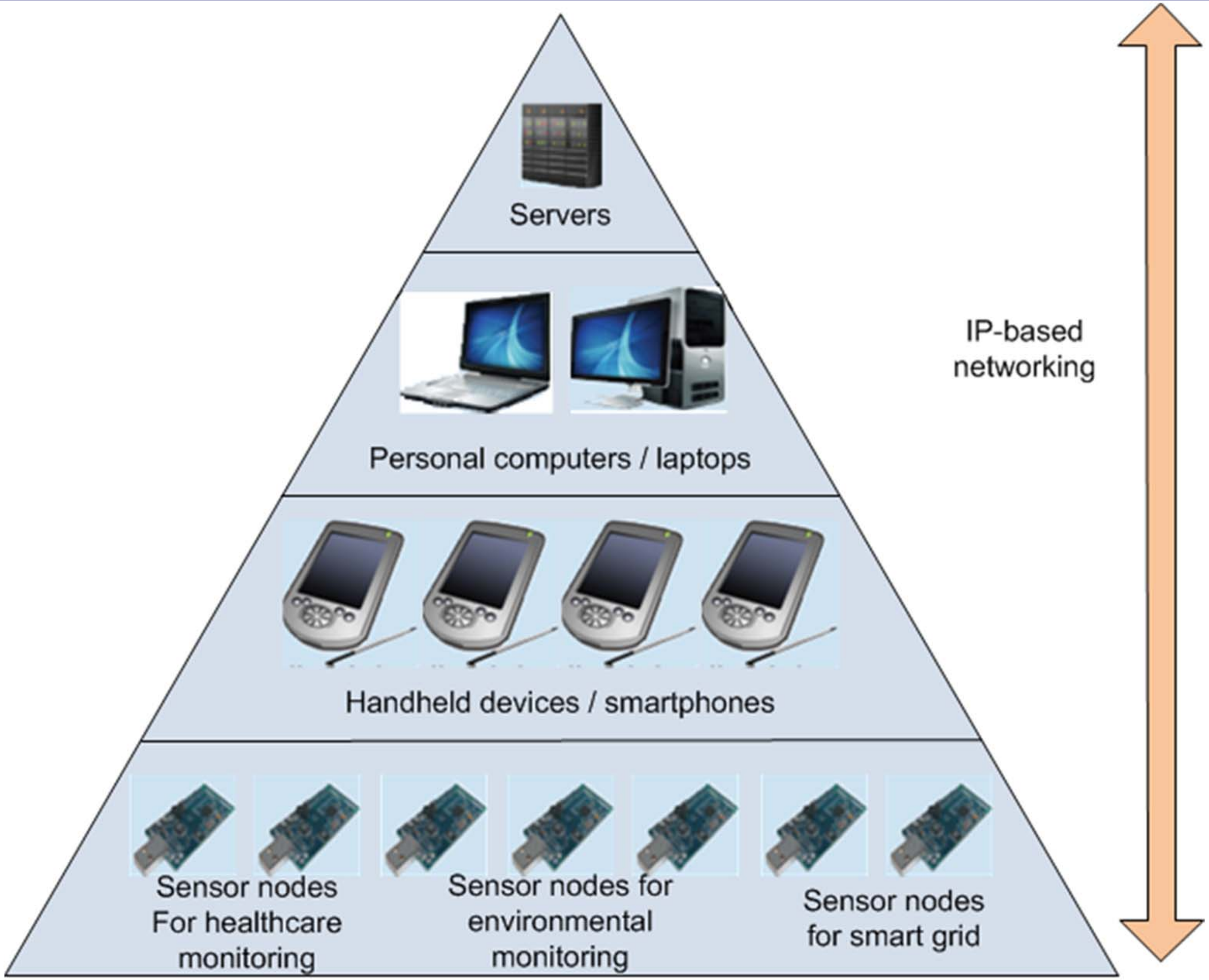
- Most of the research on joint **routing** and **spectrum allocation** does not take into account power efficiency constraints directly.
- Throughput maximization via routing-driven spectrum allocation can be interpreted as power efficiency, since more throughput is achieved using the same amount of power.


MTC user
MTC user
MTC user
Operator domain A
MTC server
Operator domain B
HeNB GW
MME/S-GW/P-GW
S1
S1
eNB
X2
S1
X2
X2
eNB
The air interface between LTE-advanced E-UTRAN and MTC device
RN
RN
S1
M2M Gateway
eNB
RN
RSU
S1
M2M Gateway
M2M Gateway
M2M Gateway
RSU
M2M Gateway
M2M Gateway

Routing Over Low power and Lossy networks (ROLL)

- There has already been a paradigm shift from early flooding-based and hierarchical protocols to geographic and self-organizing coordinate-based routing solutions
- Internet Engineering Task Force (IETF) **Routing Over Low power and Lossy networks** (**ROLL**) working group is in process of standardization of **Routing Protocol** for **Low power and lossy networks** (**RPL**)

Low-power and lossy networks connect the Internet of Things to the existing IP-based network architecture.



Conclusion

- This talk addresses the **energy efficiency** of cellular communication systems, which is becoming a major concern for network operators to not only **reduce the operational costs**, but also to **reduce their environmental effects**.
- This talk briefly discusses some **current technology** with respect to some aspects related to **green communications**.

Homework #10:

1. Describe energy saving architecture in Base Stations.
2. Describe the energy saving techniques in Green Communication.
3. Why cognitive radio technique can reduce the power consumption?