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Chapter 2: Green Cellular Networks

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Global climate change/ The cause of global warming

- Global climate change

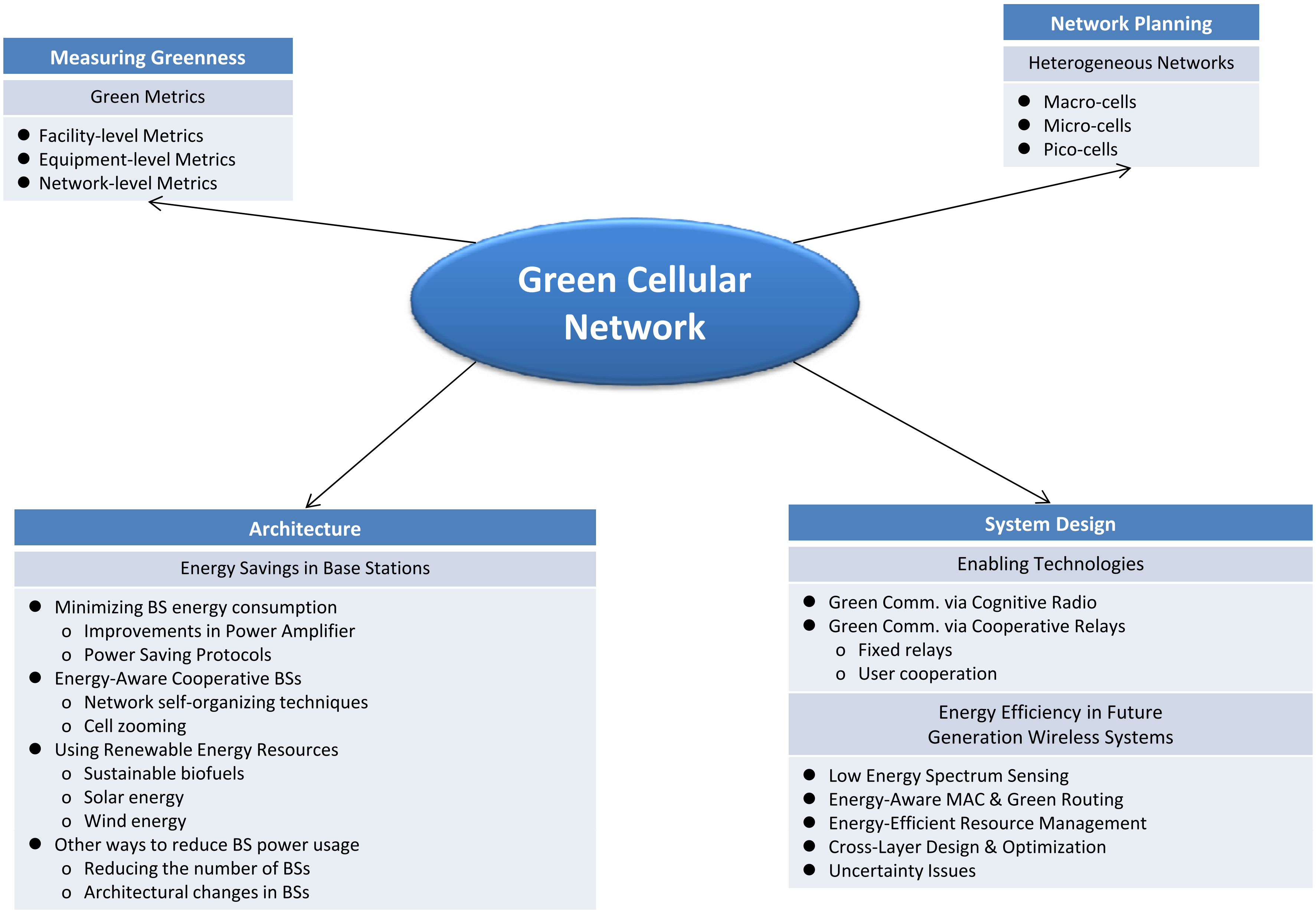


- The cause of global warming

Outline

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

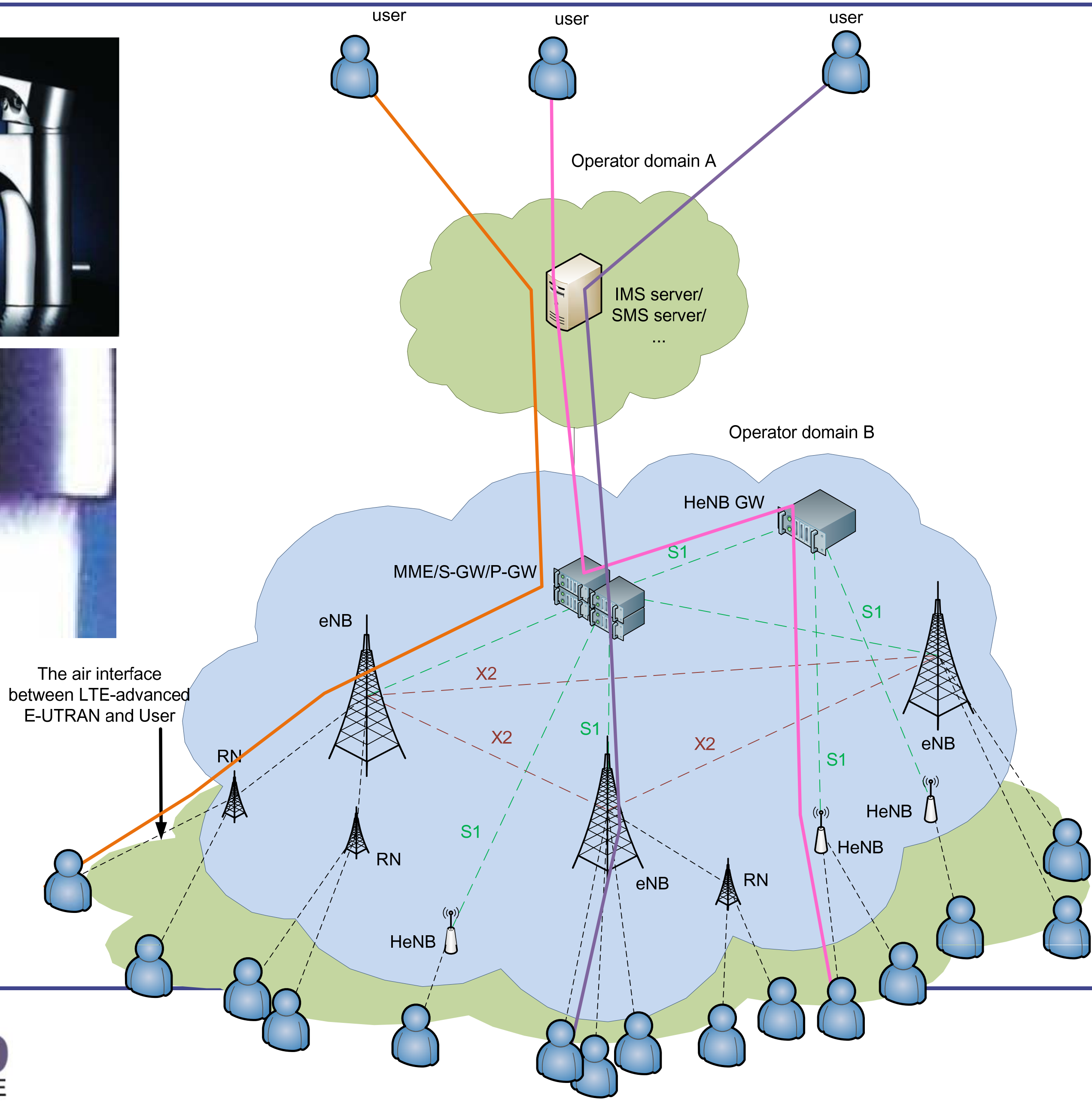
Technical roadmap for Green Cellular Networks: A taxonomy graph



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.

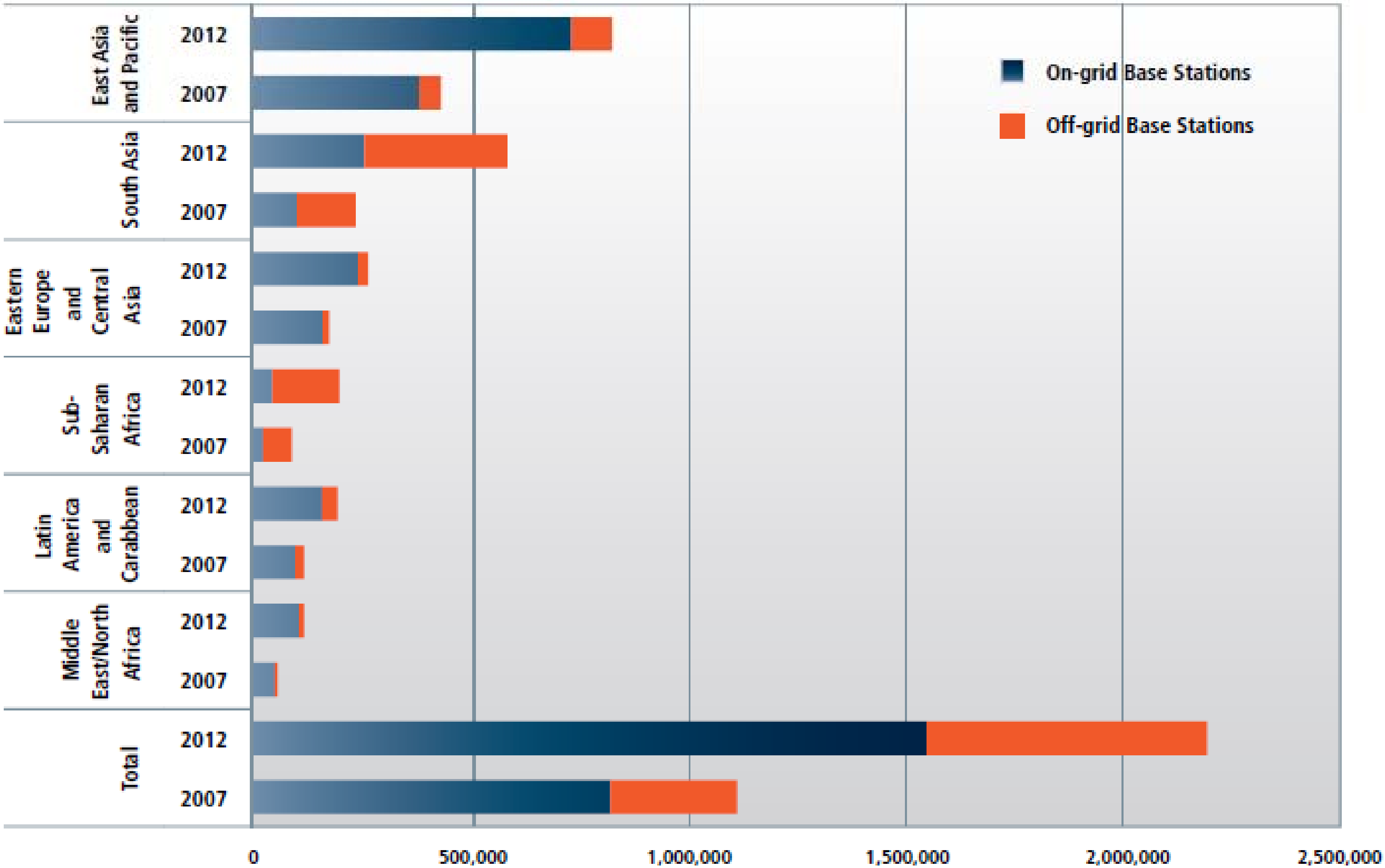
H2H communication



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

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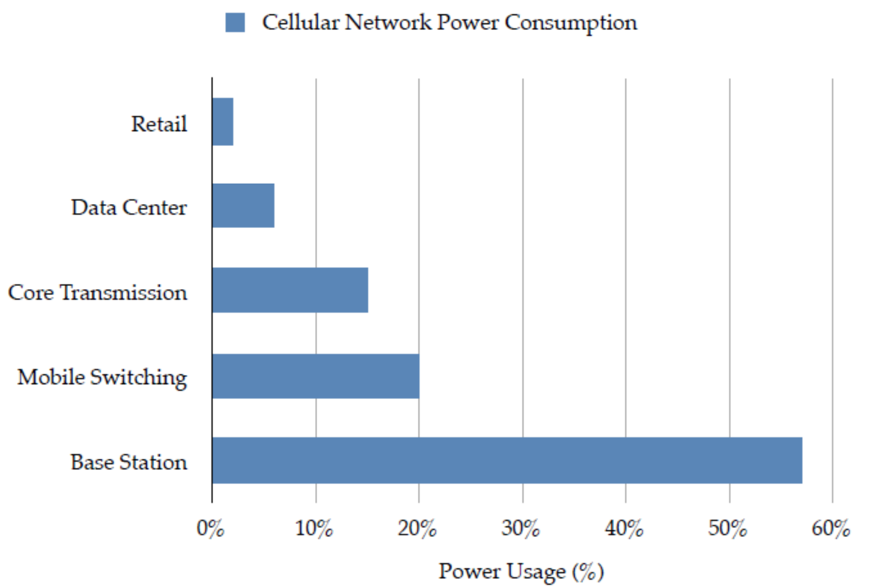
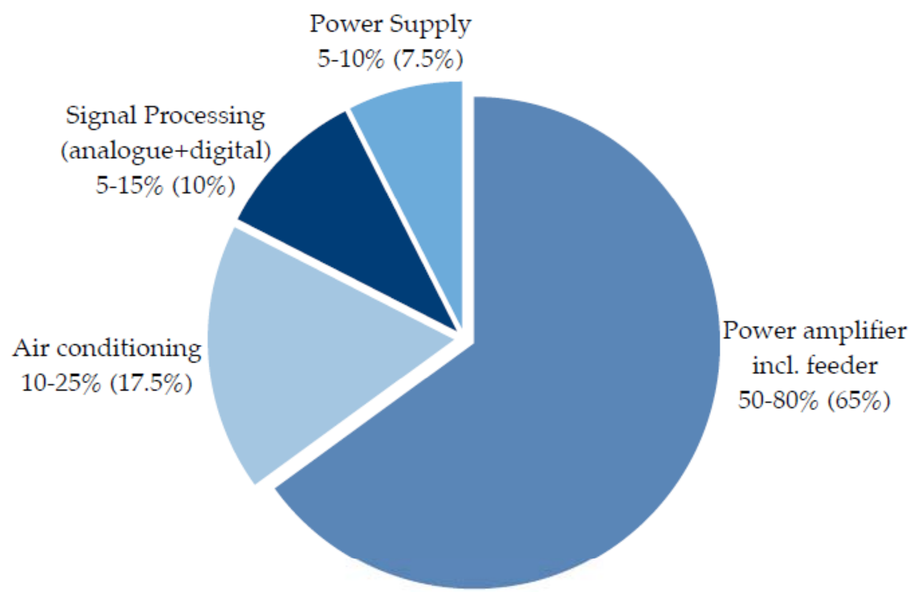
Cont.

- "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)

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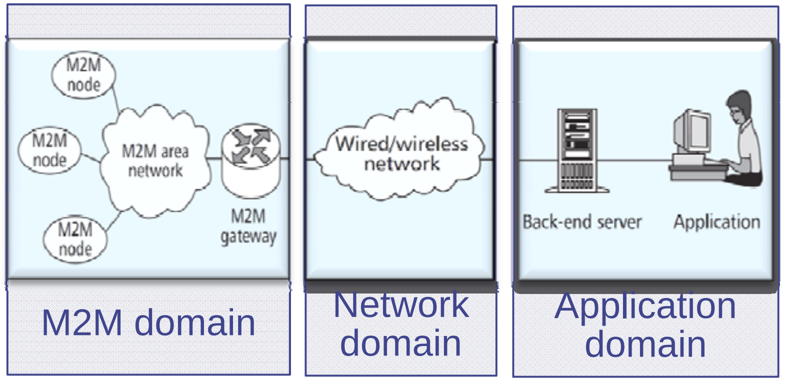
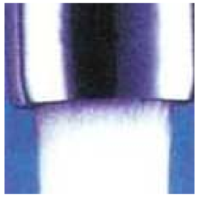
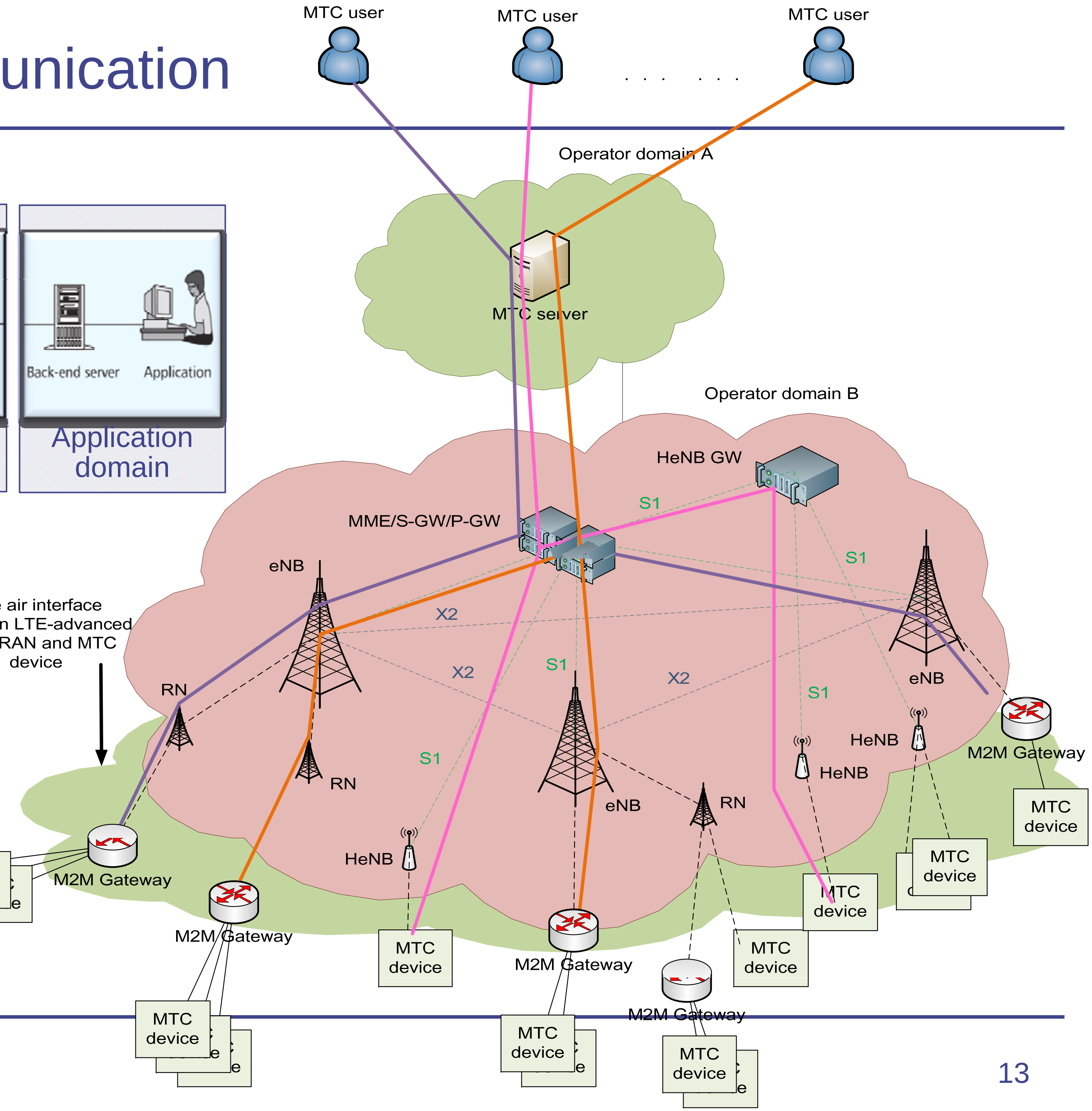
M2M Communication

- 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.

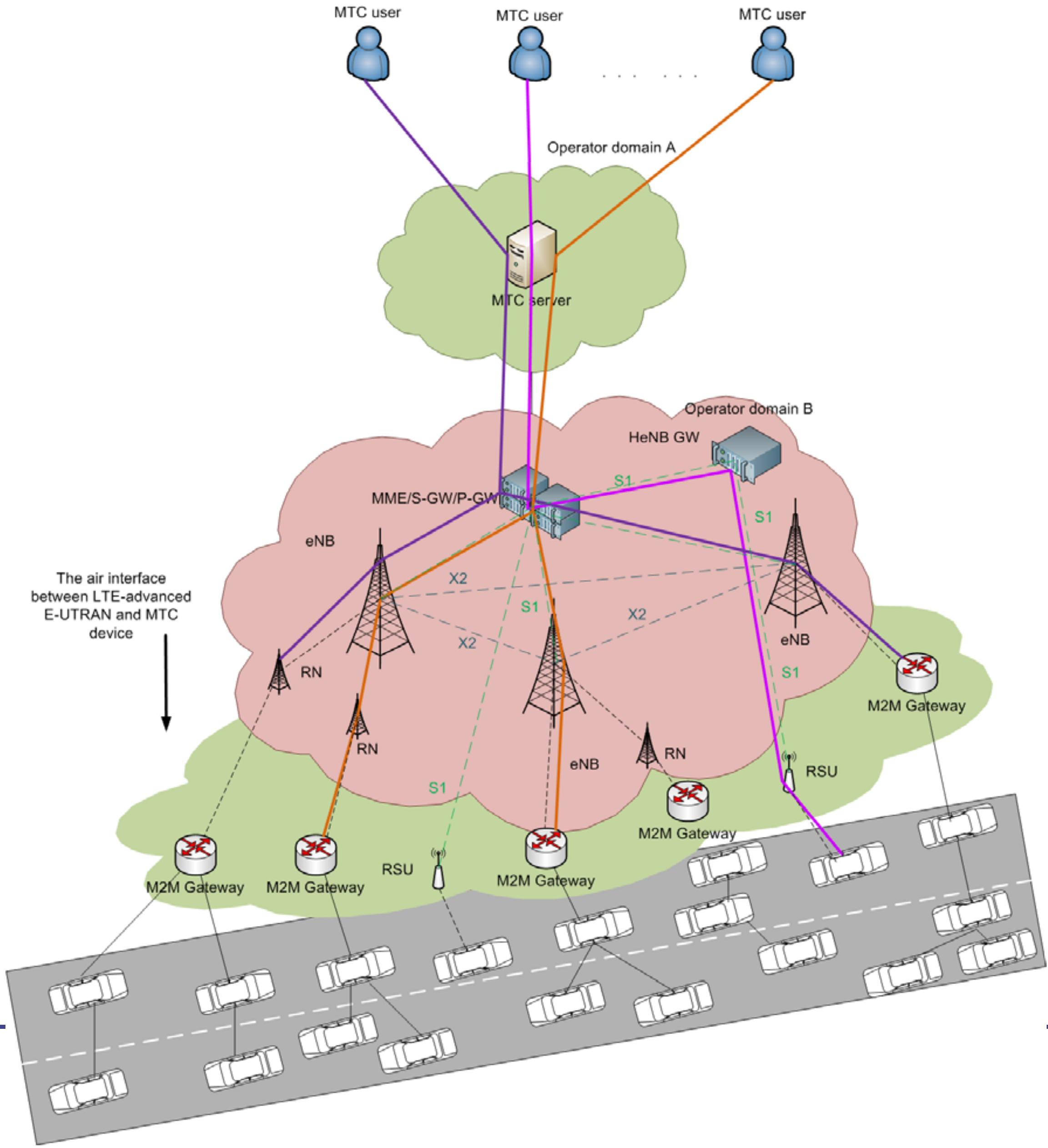
M2M communication







Vehicular M2M communication



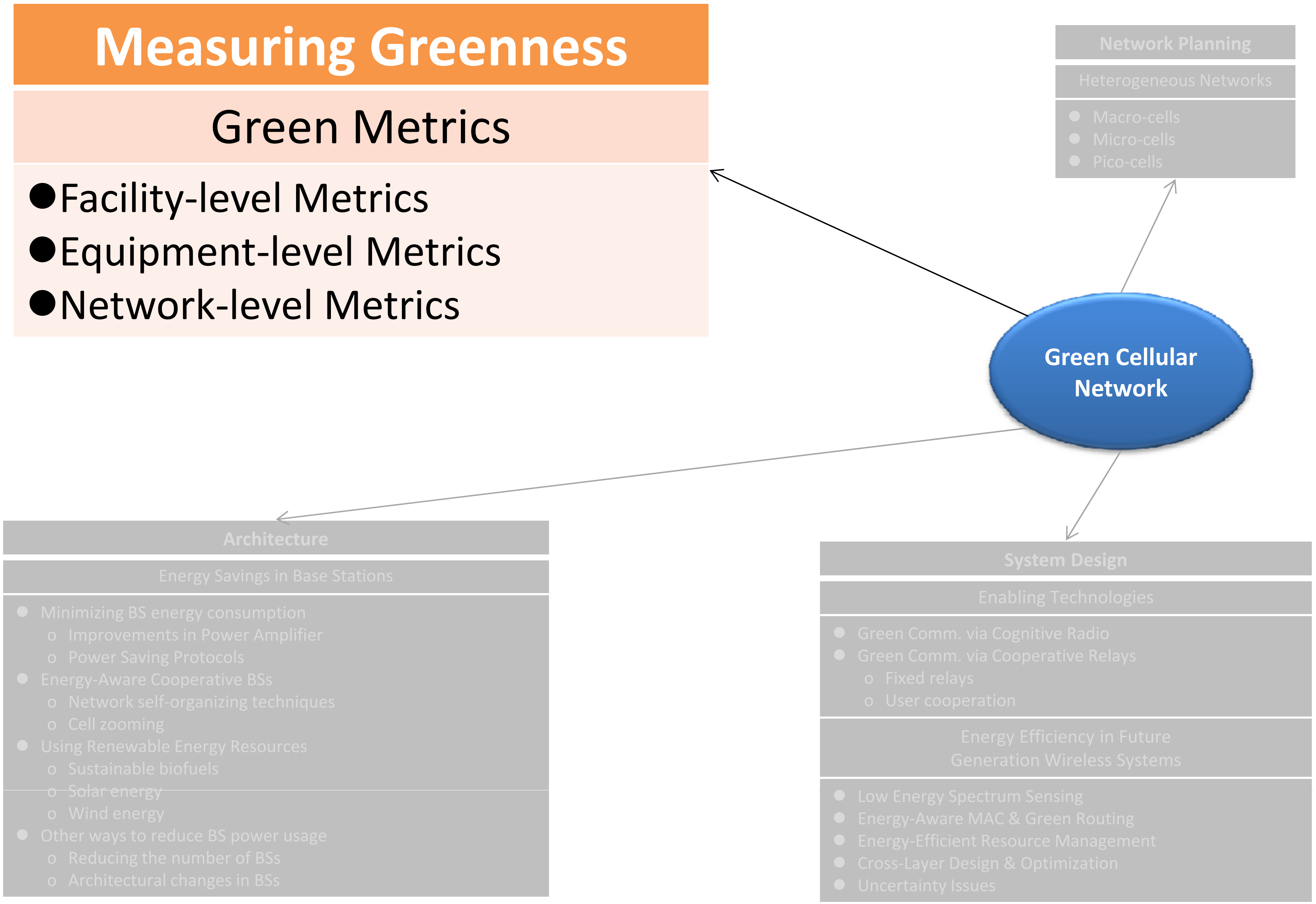
Cont.

- 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

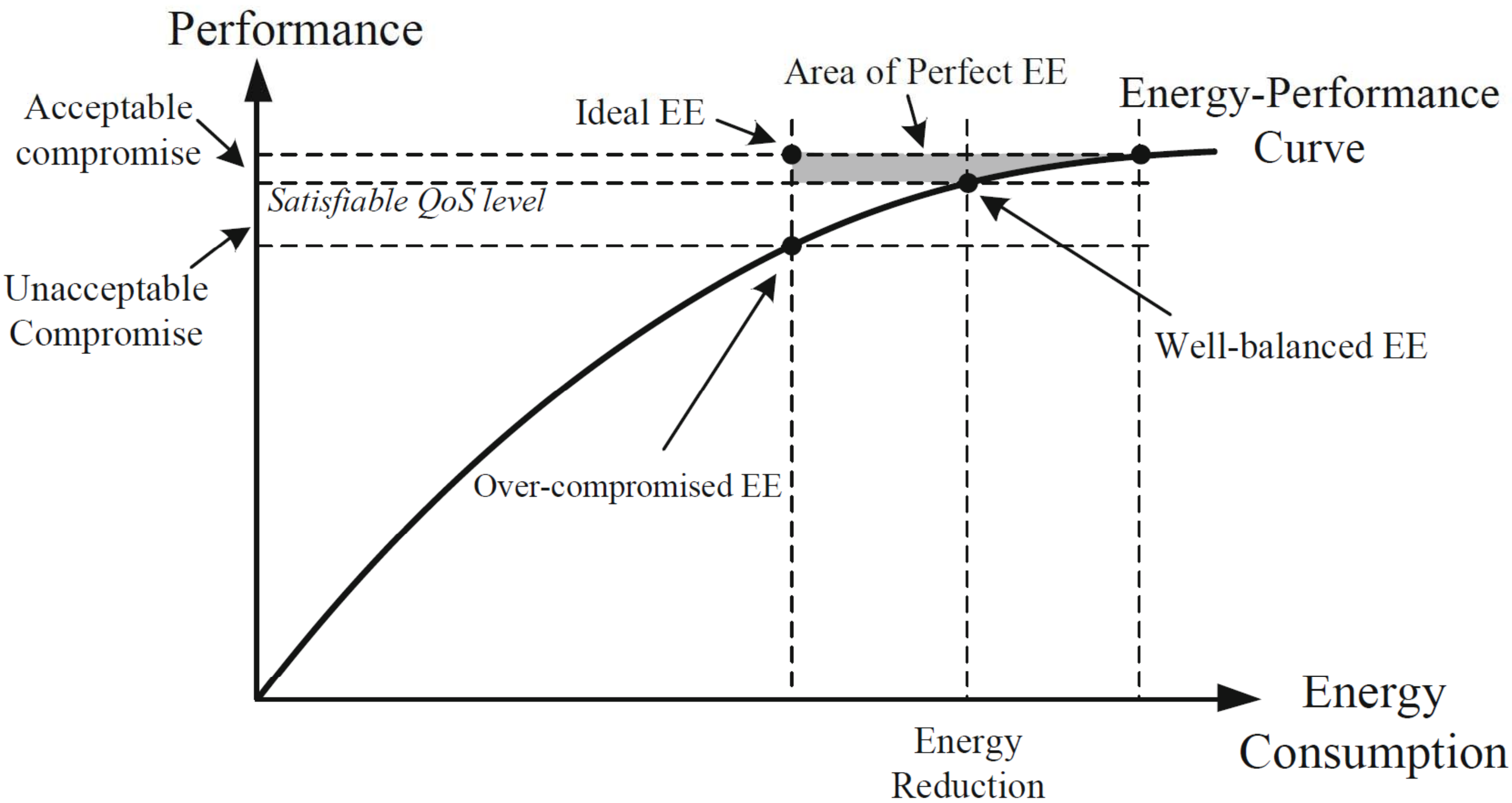


Table I. Some energy efficiency metrics

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)

- Measuring Greenness
- **Architecture**
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- System Design

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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

Green Cellular Network

Measuring Greenness

Green Metrics

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

Network Planning

Heterogeneous Networks

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

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.

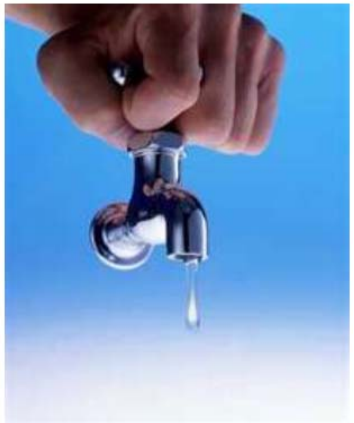
Cont.

- 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

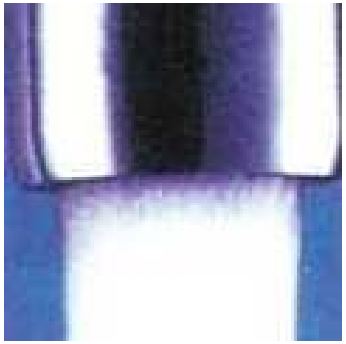
- The energy consumption of a typical BS can be reduced by improving the **BS hardware design** and by including *additional software* and *system* features to balance between energy consumption and performance.

- 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%.



MIMO antennas

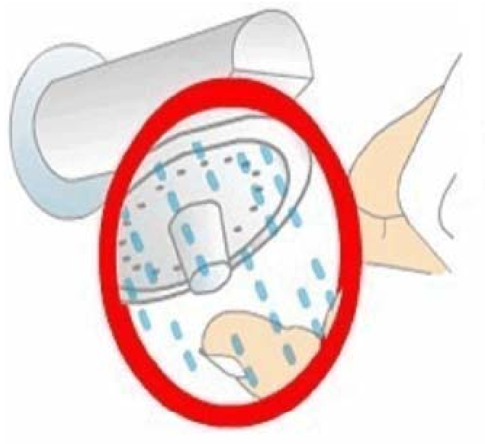
- With the high data requirements, although BSs and mobile units (MU) employing newer hardware (such as **multiple-input and multiple-output** (MIMO) antennas) increase spectral efficiency allowing to transmit more data with the same power
  - Power consumption is still a significant issue for future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

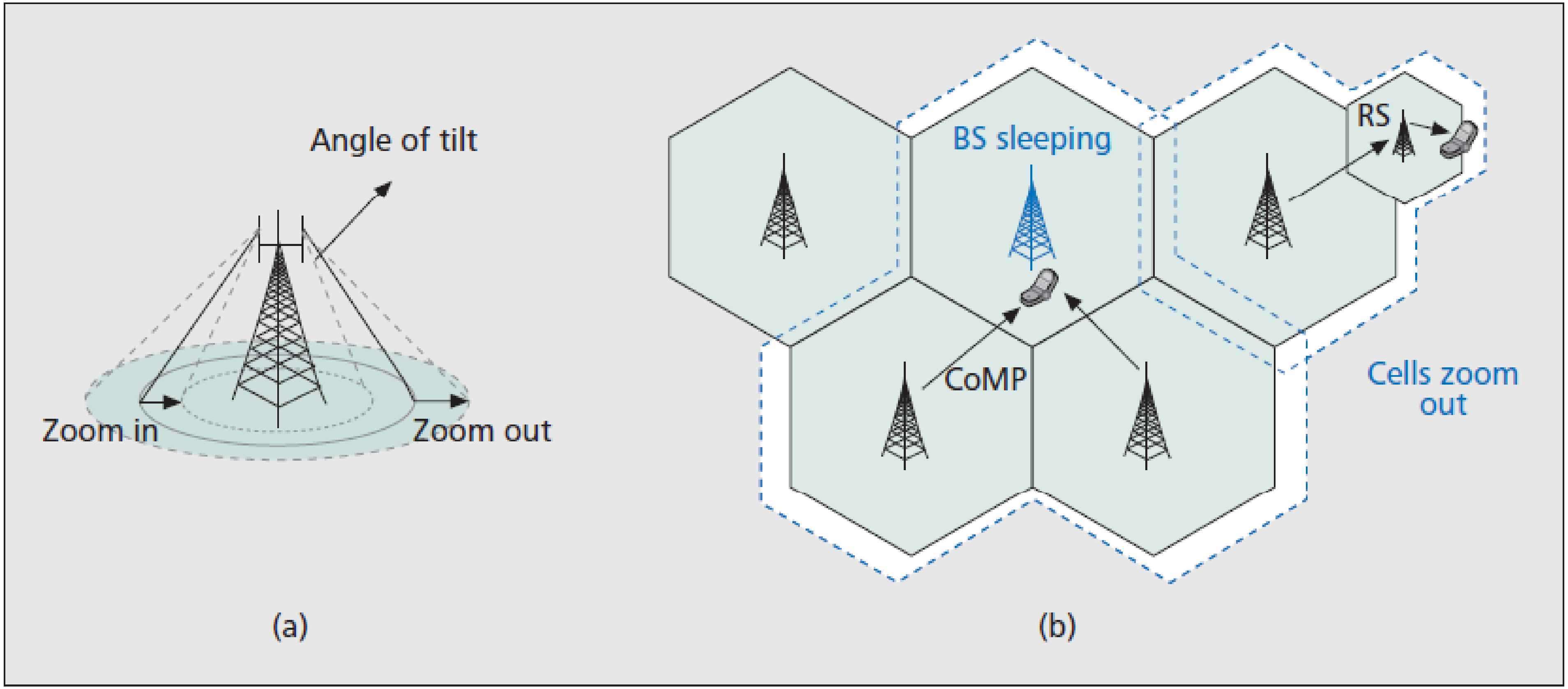
Self-organizing networks (SON)

- 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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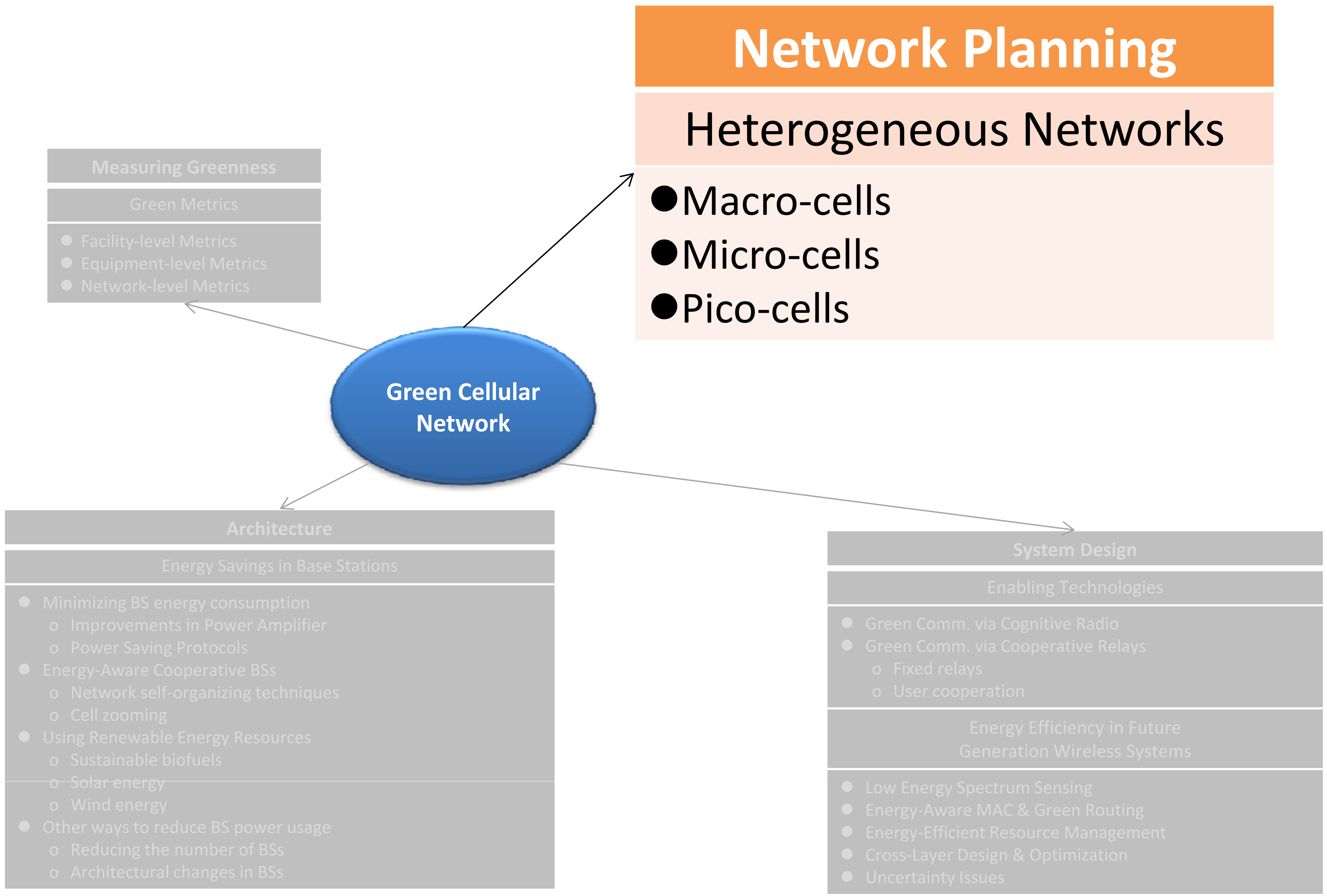
Technical roadmap for Green Cellular Networks: A taxonomy graph



4. Network planning:

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

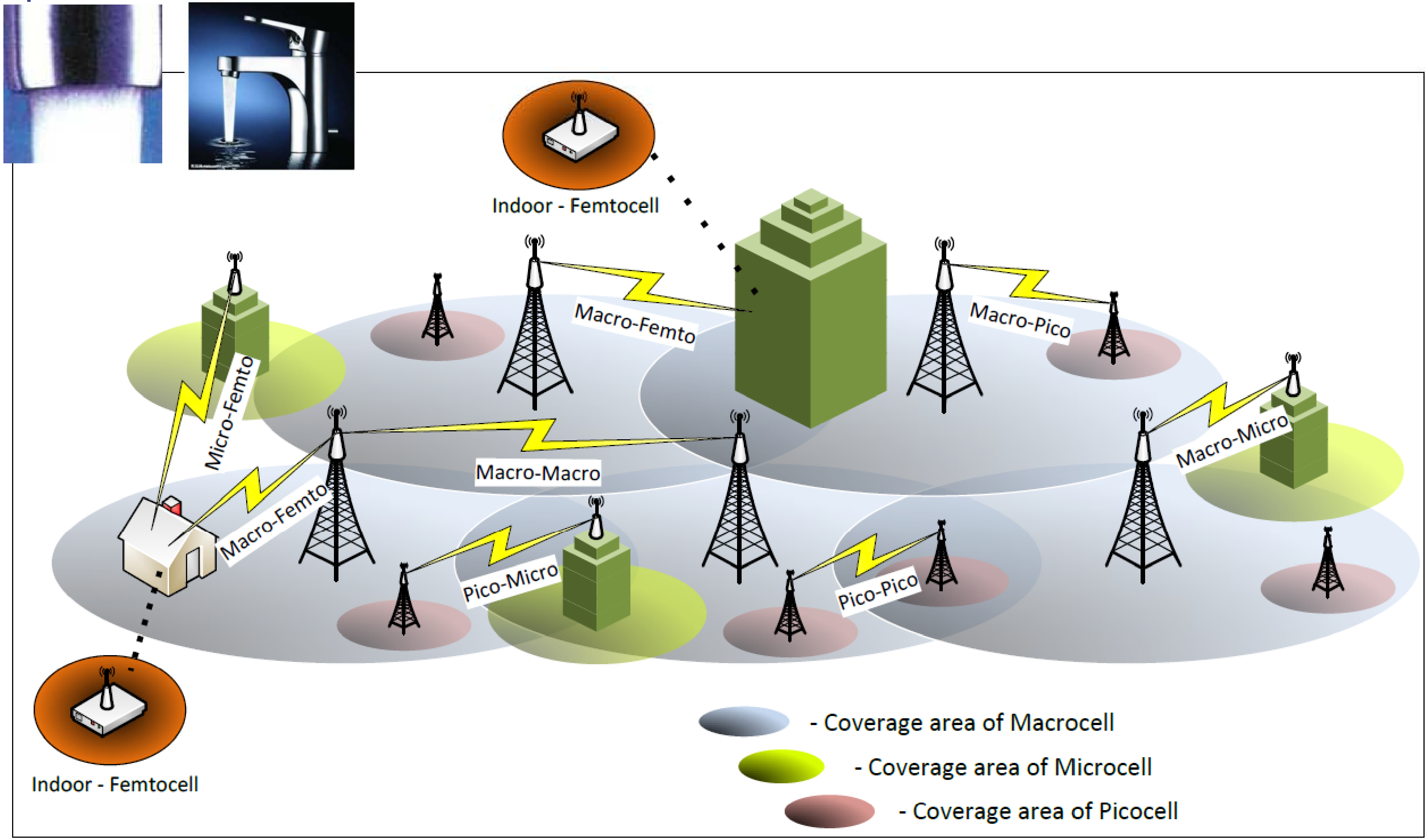
Heterogeneous network deployment

- 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.

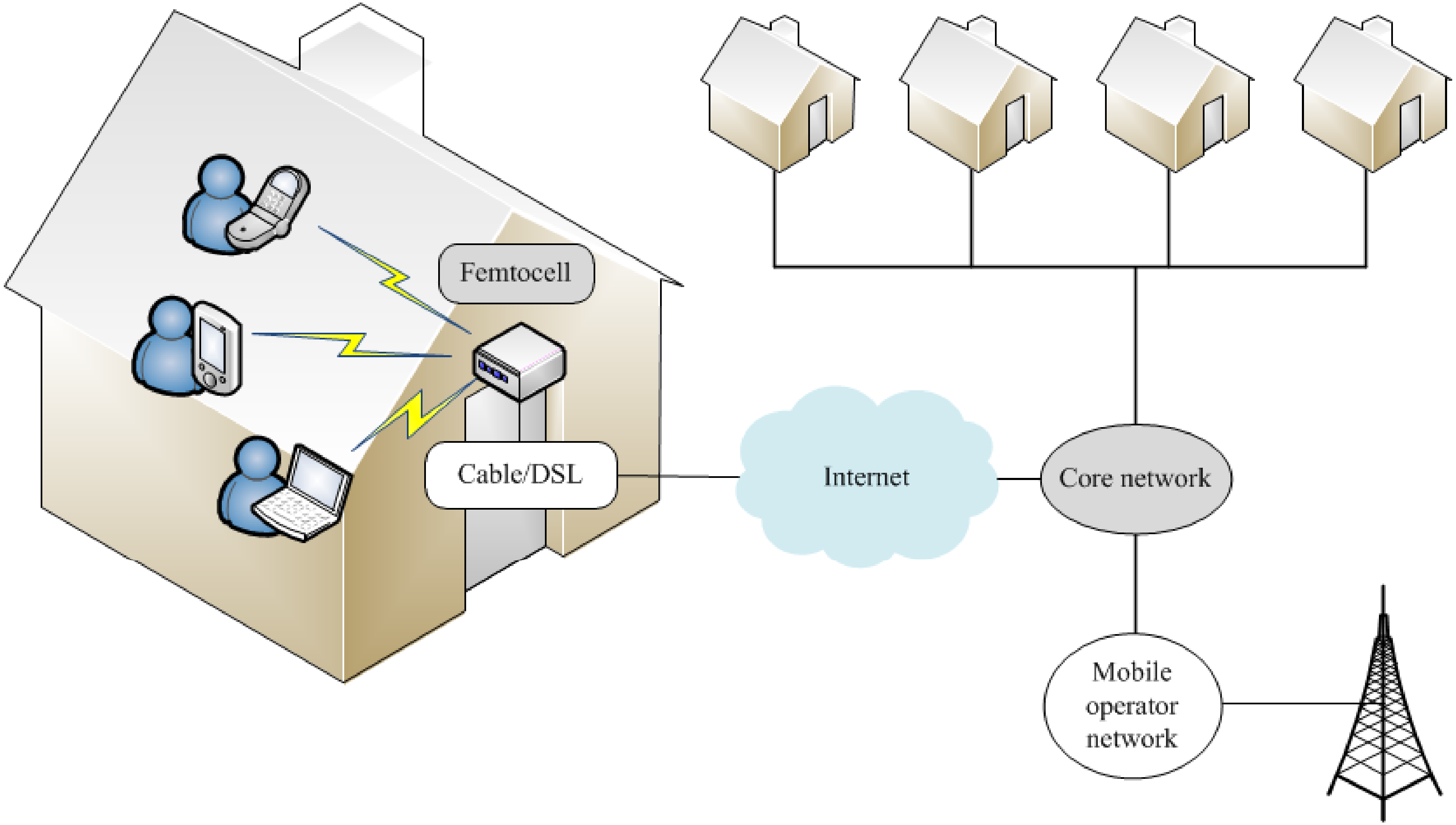
Fig . A typical heterogeneous network deployment



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**

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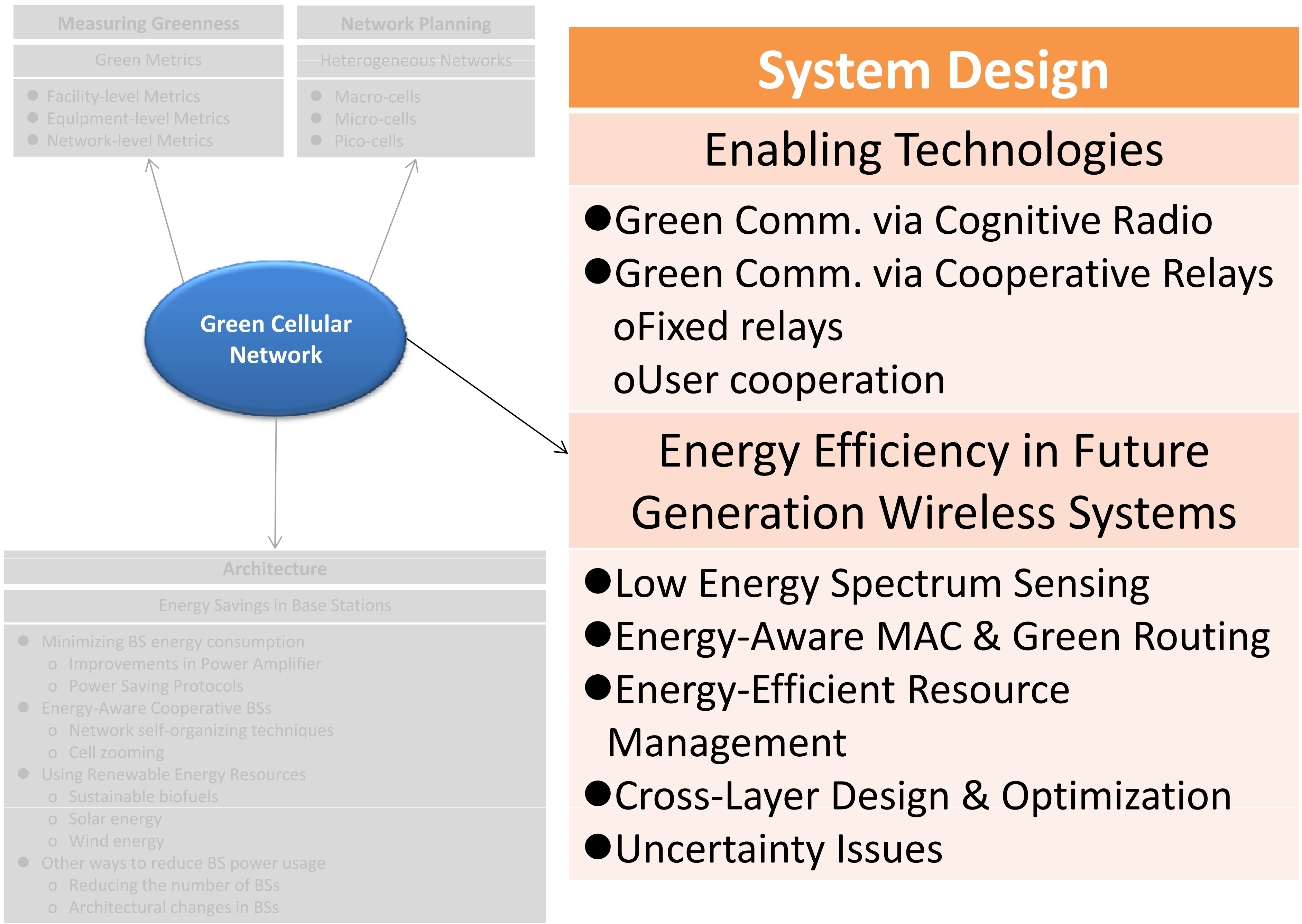


5. System Design

- **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

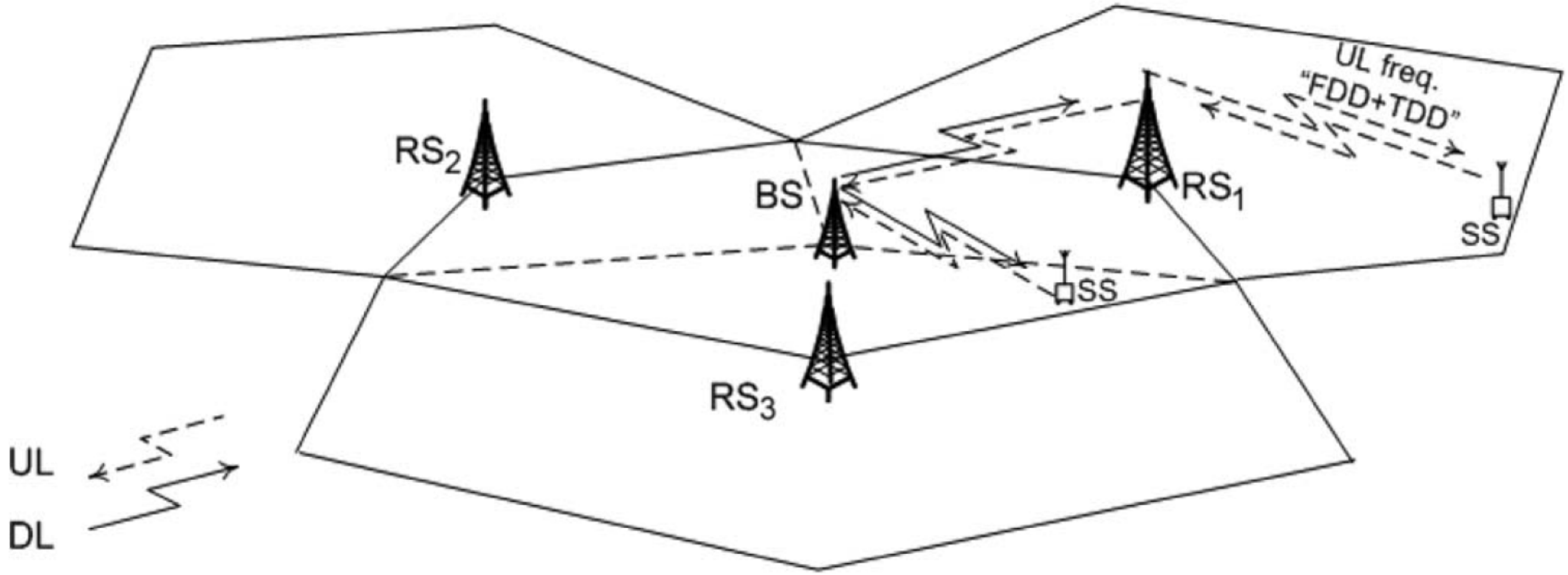
Cooperative Relays to deliver green communication

- 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.

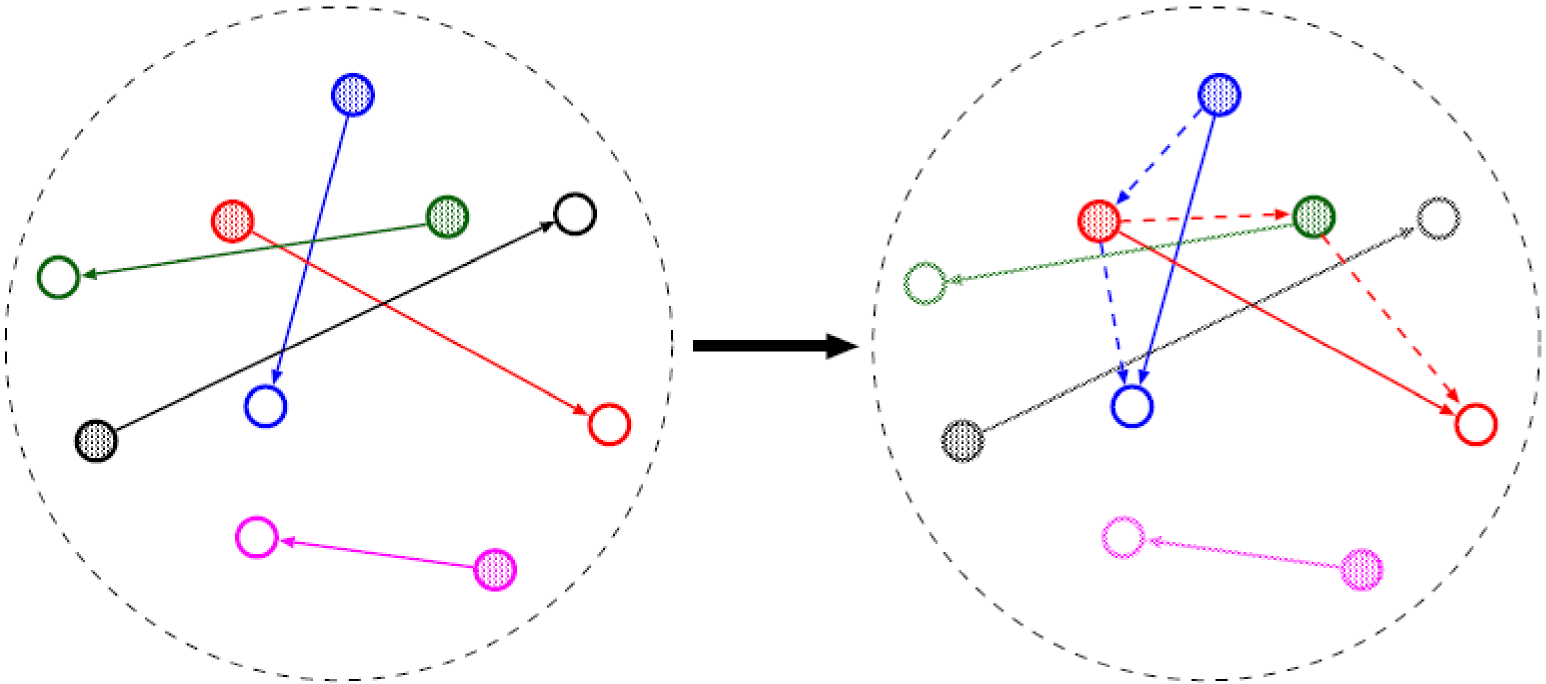
BS, RS, and respective “hexagonal” coverage areas.



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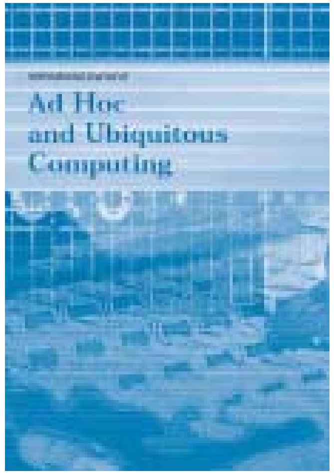
- In a very recent work by Nokleby and Aazhang, this fundamental question has been posed: **whether or not user cooperation is advantageous from the perspective of energy efficiency**.
  - A game-theoretic approach is proposed to give **users** incentive to act as **relays** when they are idle, and it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

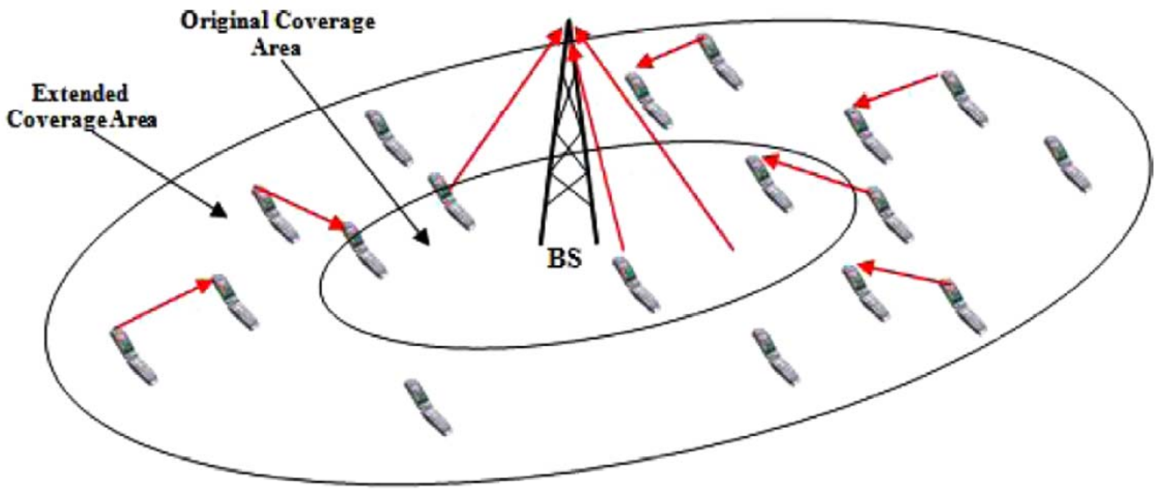
- **User cooperation** in which **selfish users** find cooperation favourable to their energy concerns, has recently been considered, but still is an open question.

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

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

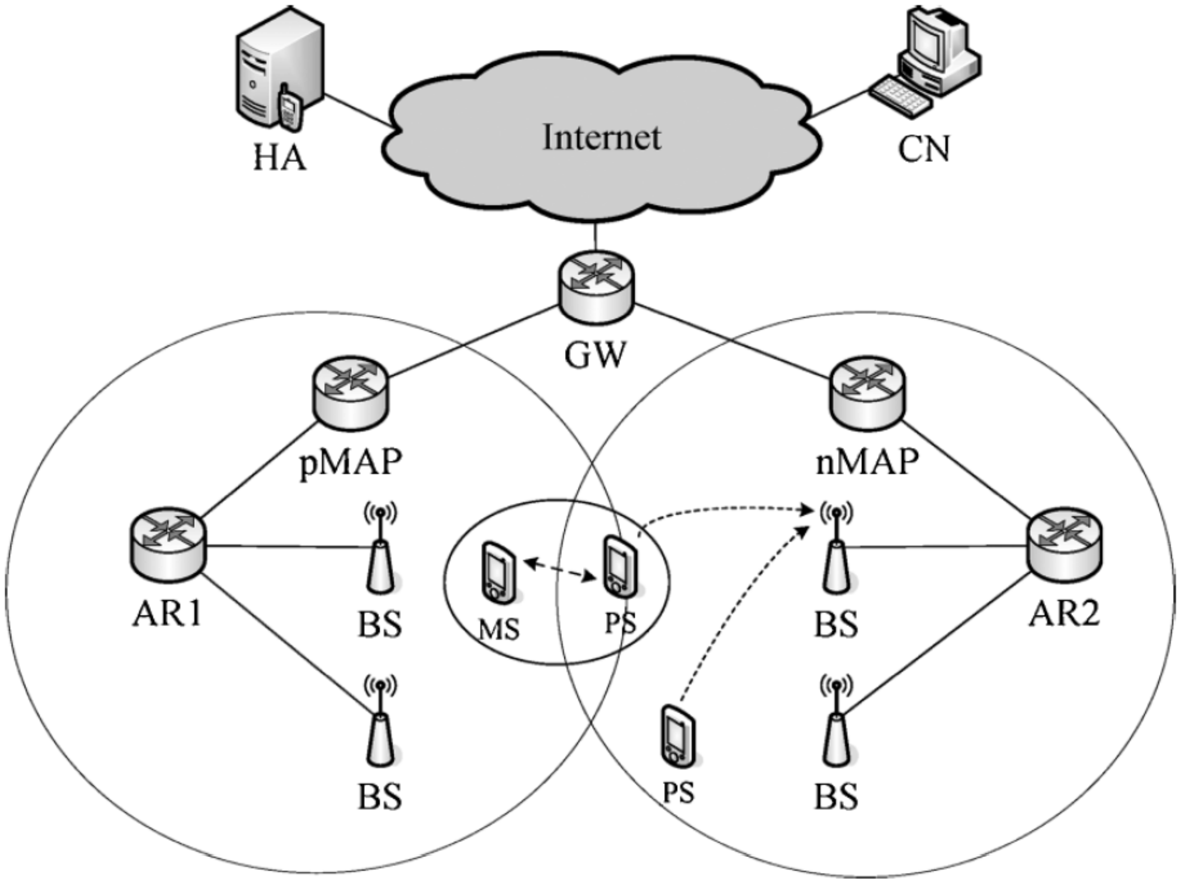


- Barnawi, A. and Gardiner, J. (2009) *Method and Apparatus for Supporting Ad-Hoc Networking Over UMTS Protocol, patent,* **United States Patent** Application 20090040985, 12/02/2009.



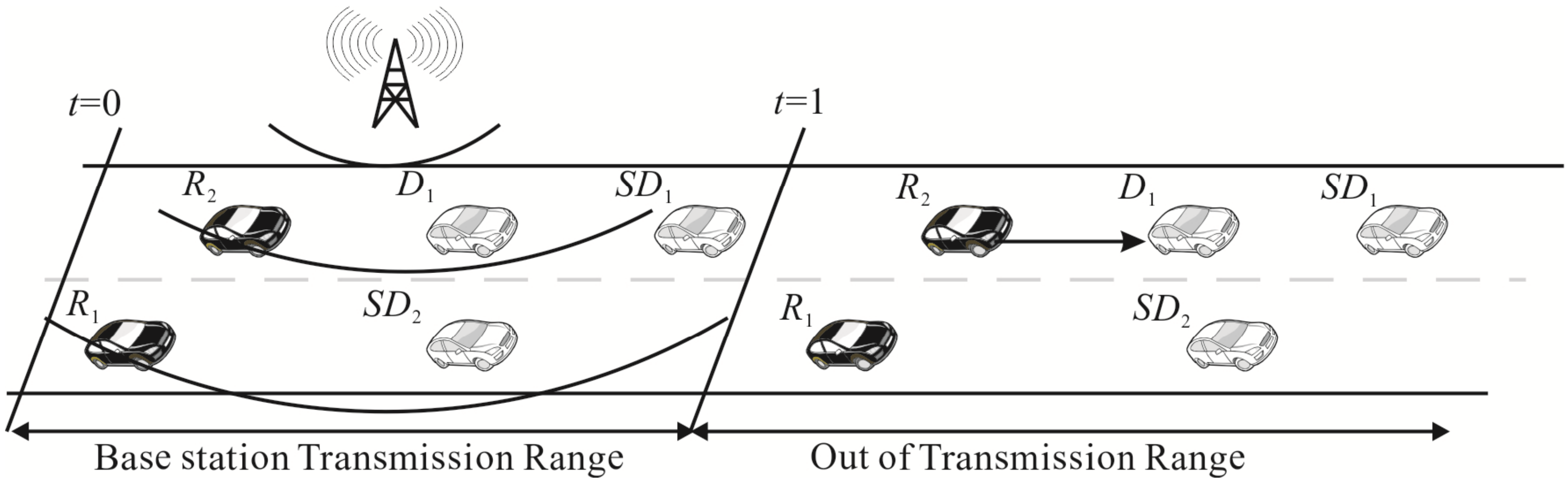
Our Result: A Cross-Layer Partner-Assisted Handoff Scheme in IEEE 802.16e

- 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.

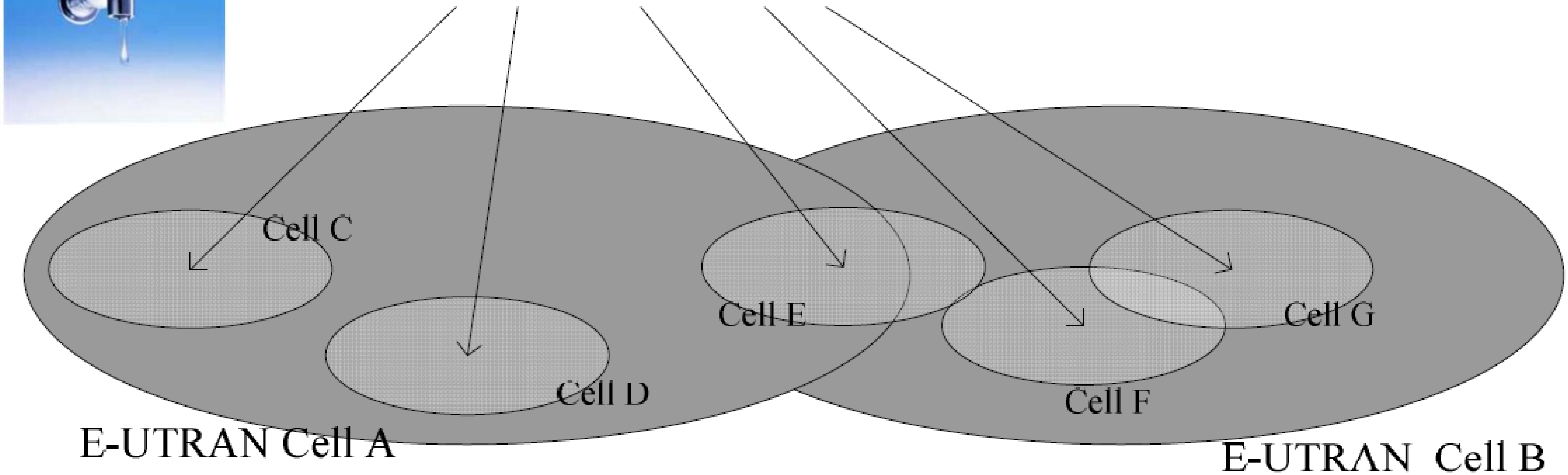


■ Energy Saving for E-UTRAN (3GPP LTE)

- 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.

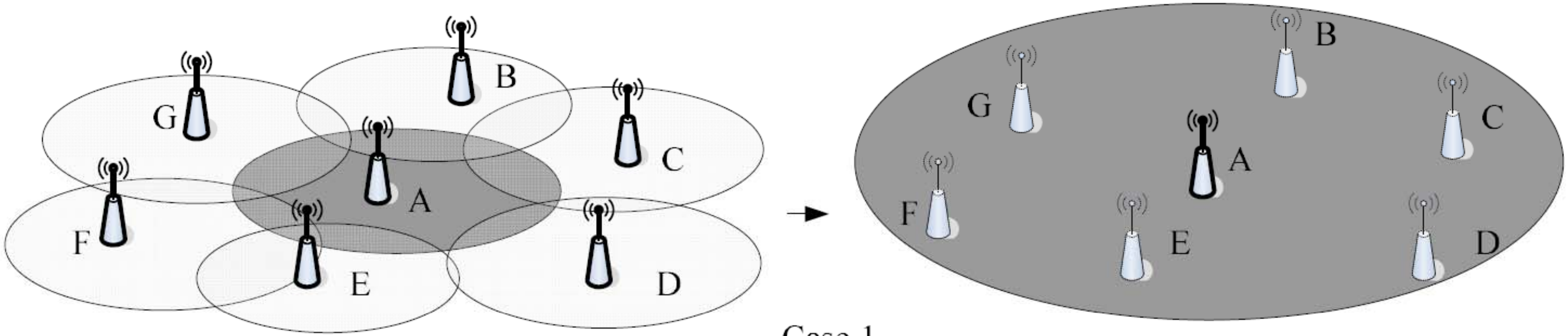
Inter-eNB scenario 1

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.

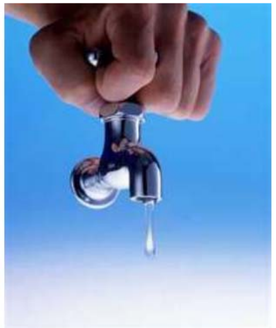
Inter-eNB scenario 2: **Case 1**

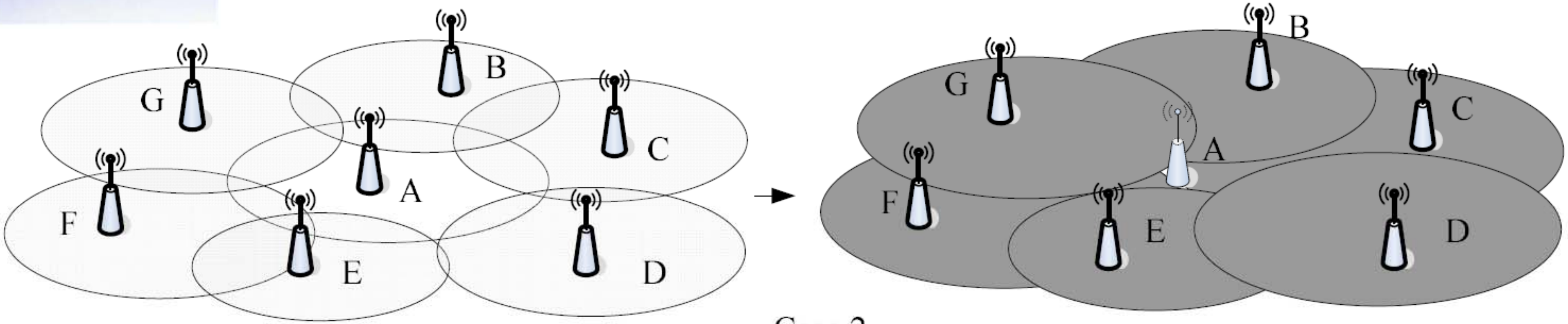


Case 1

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**





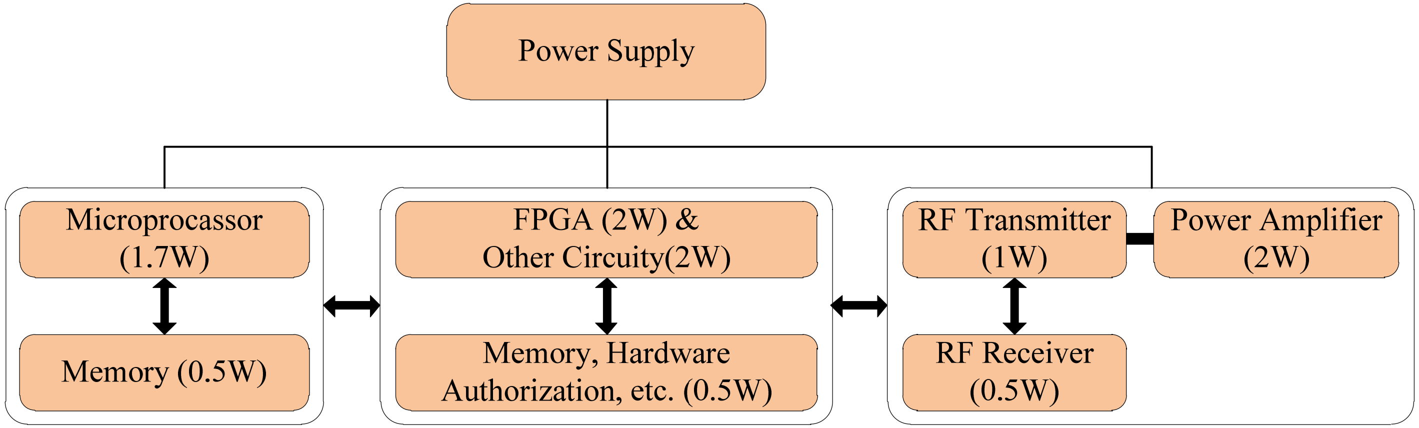
Case 2

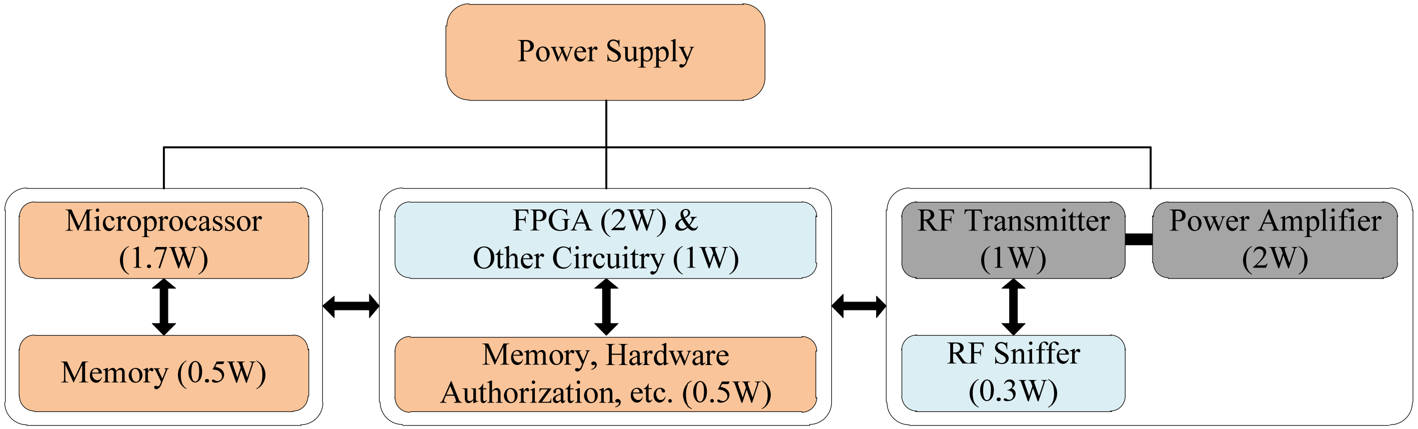
At **off-peak** time, energy saving cells may enter dormant mode, while the basic coverage is provided by **several compensation cells** (case 2).

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.

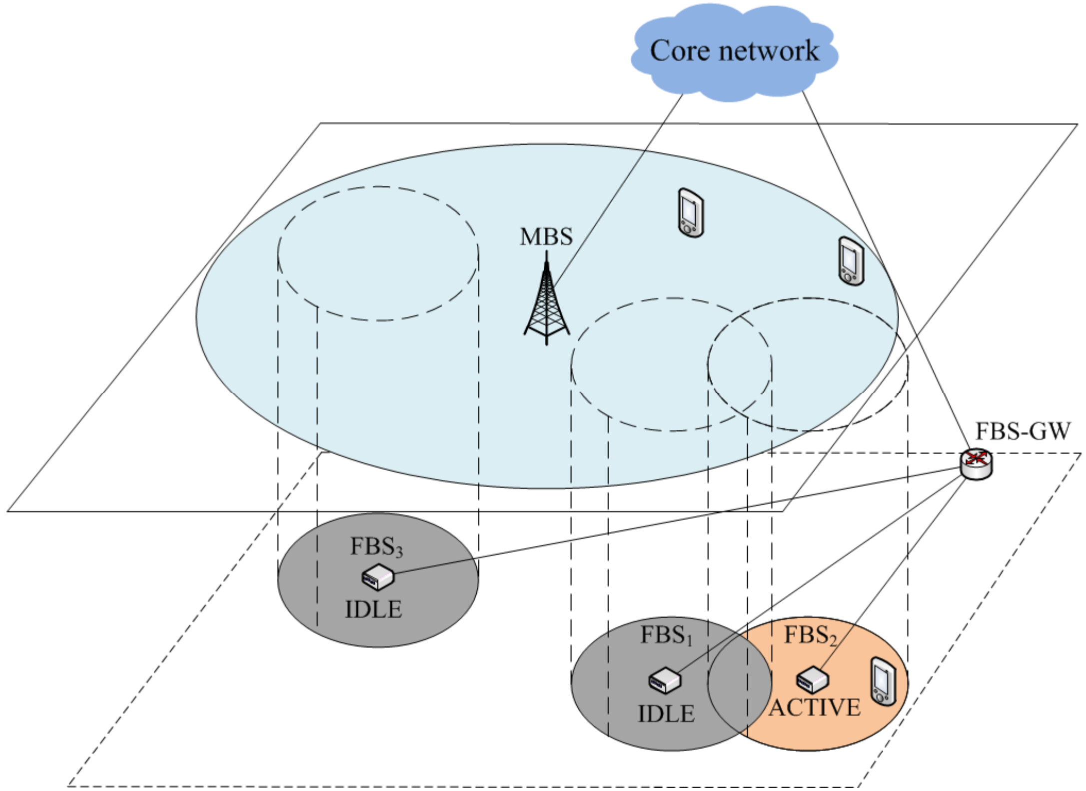
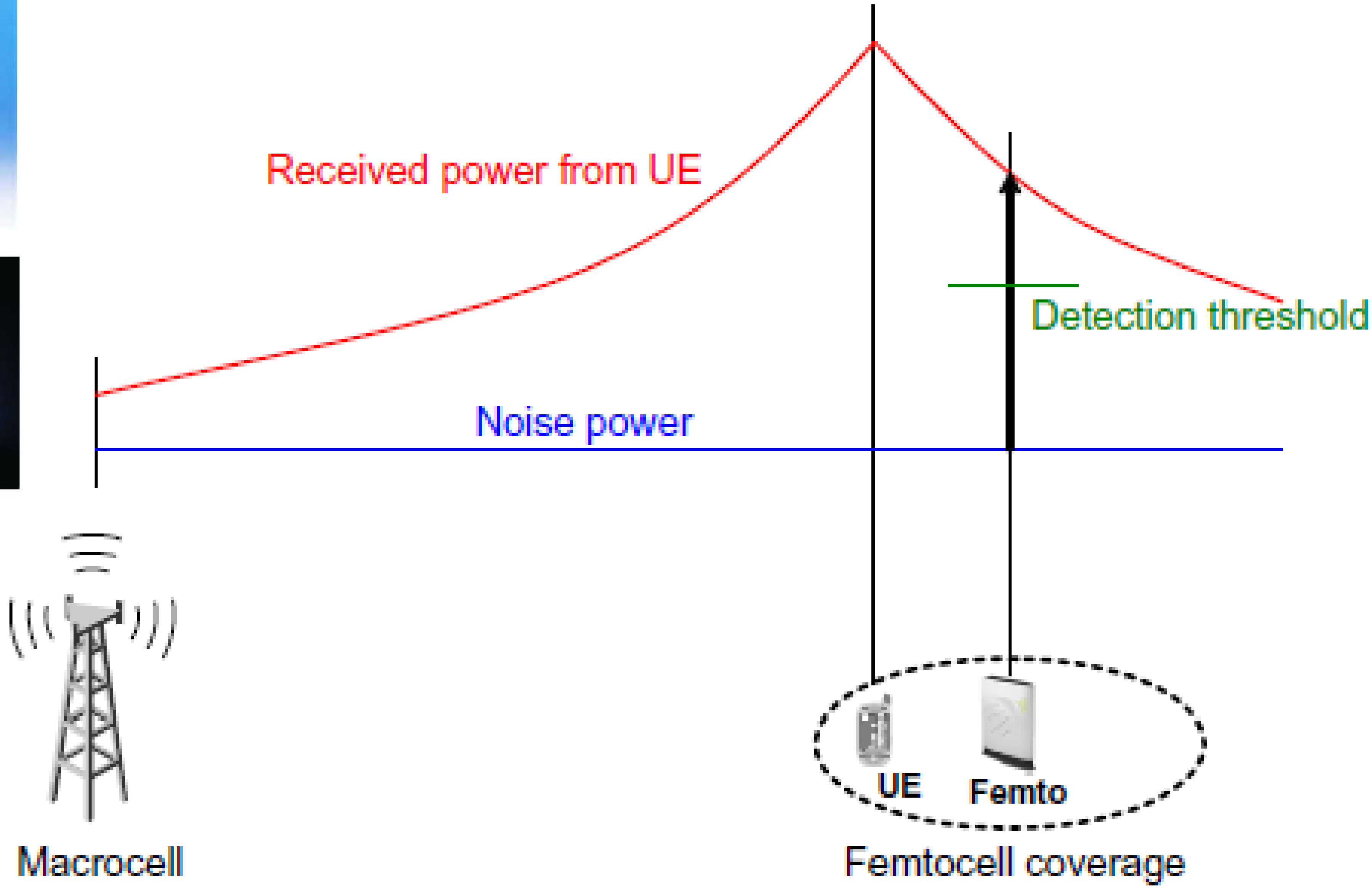
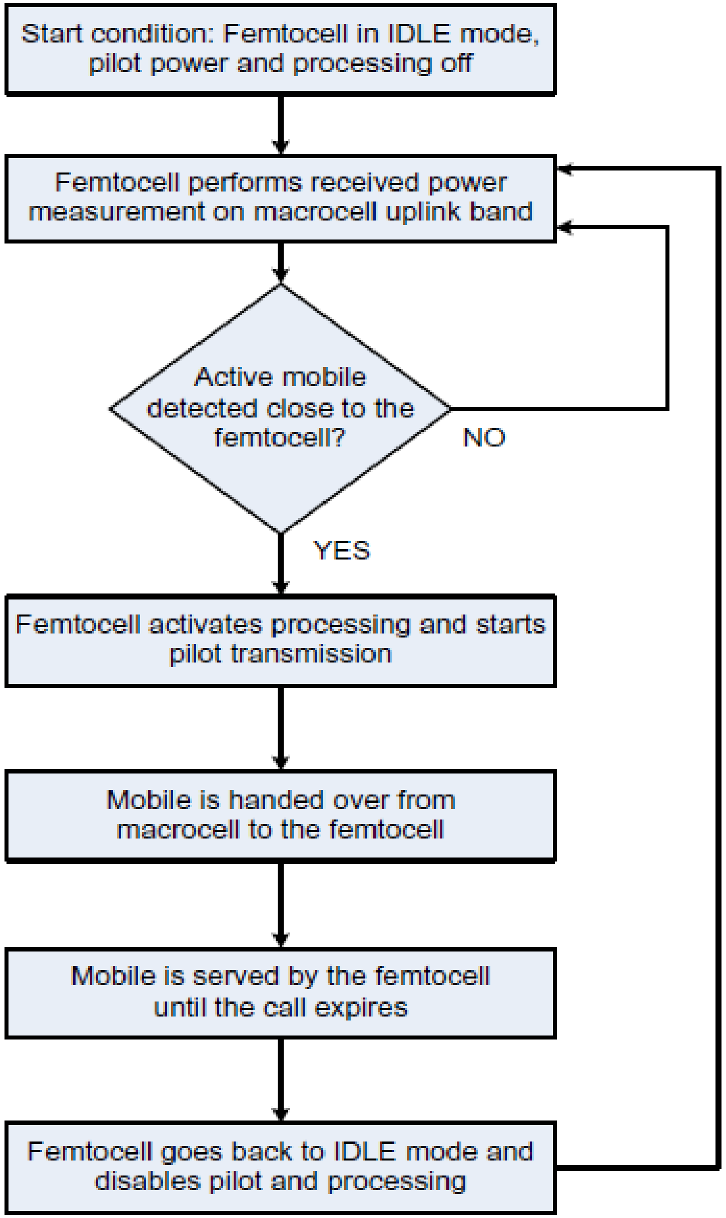


Illustration of noise rise measured at the femtocell

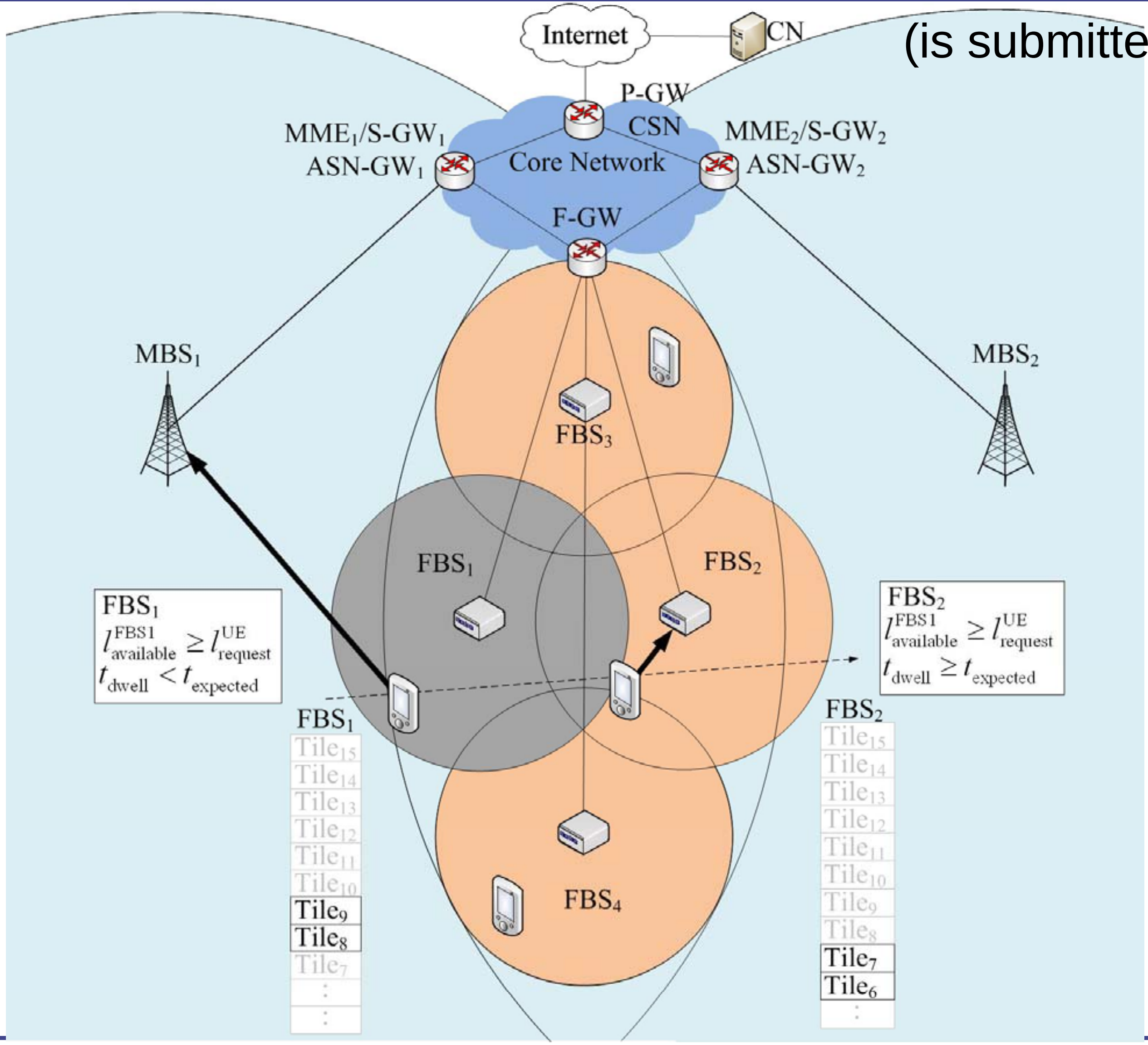


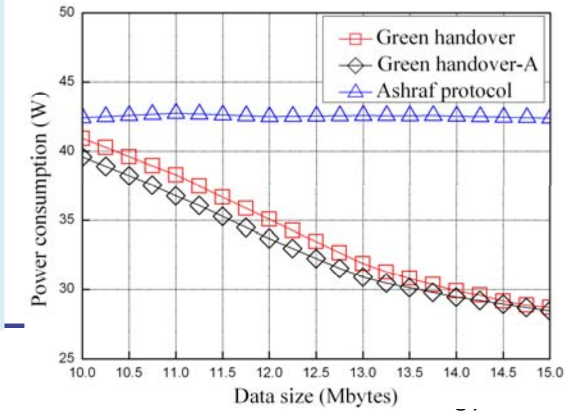
Flowchart of the IDLE mode procedure



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

(is submitted to IEEE WCNC 2012)

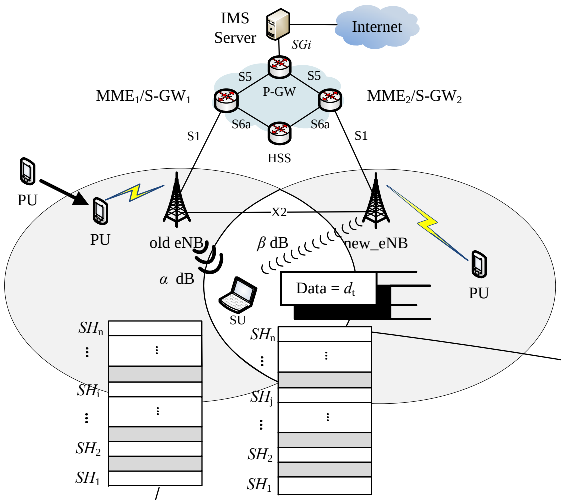




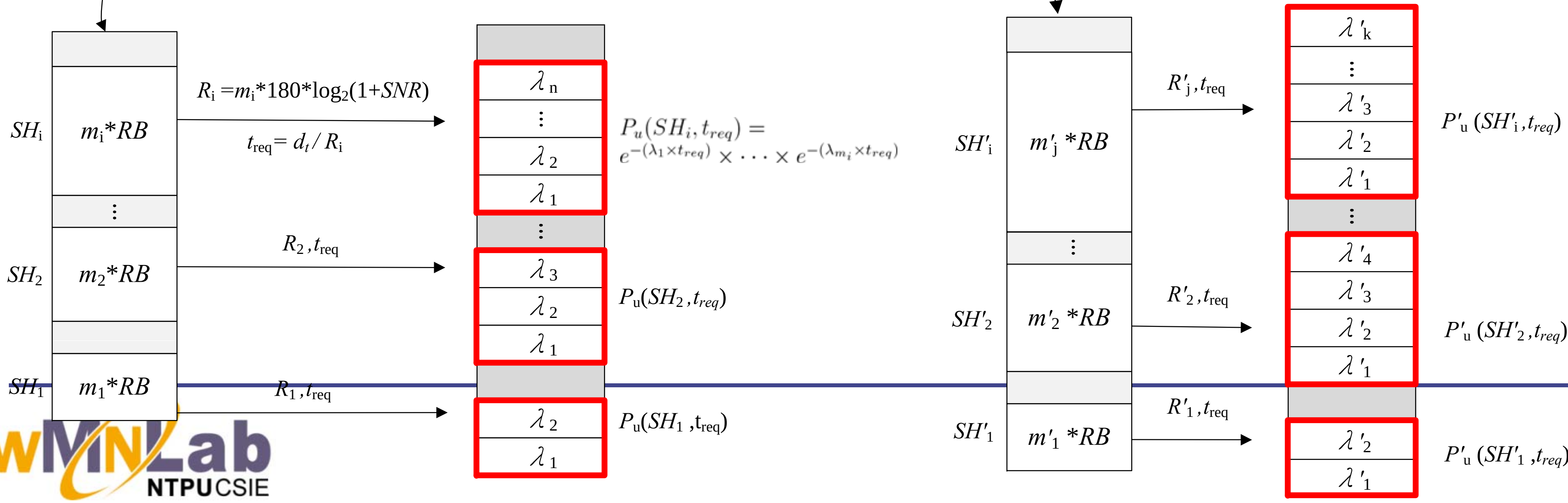
Green communication via **cognitive radio**

- 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

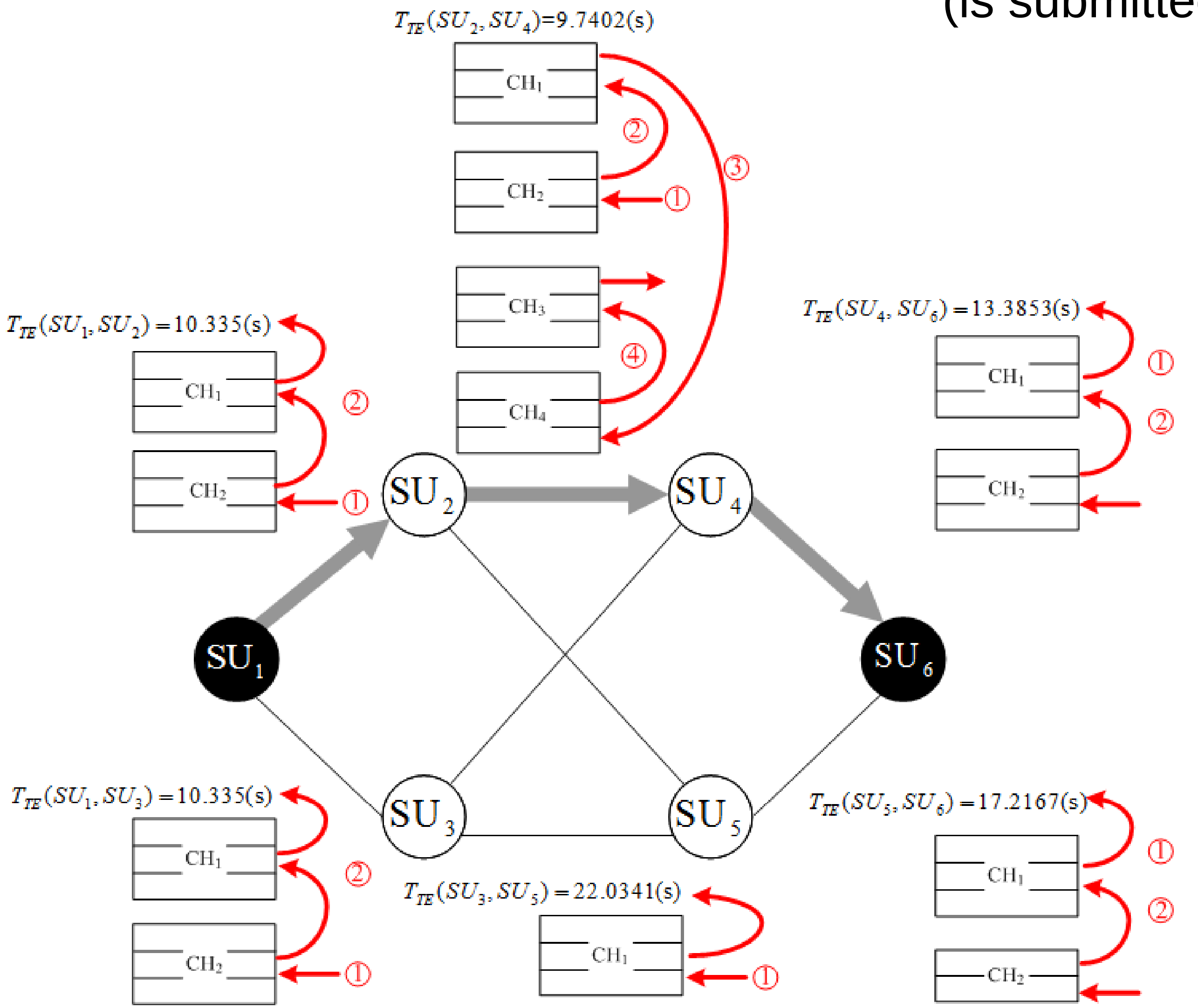


Published at Simulation Modelling Practice and Theory, 2011.



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.

WMNLab NTPU CSIE

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.

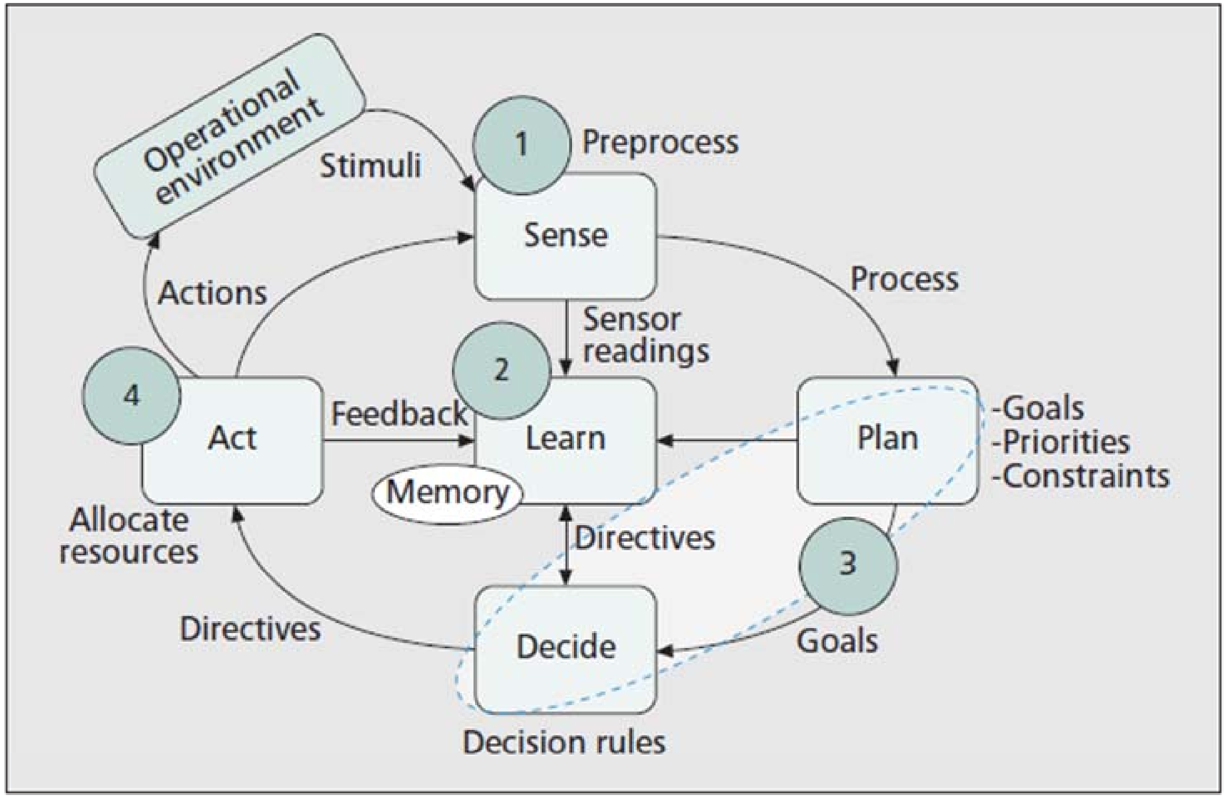
- One of these objectives can be **power saving**. It has been shown in recent works that structures and techniques based on cognitive radio reduce the energy consumption, while maintaining the required quality-of-service (QoS), under various channel conditions.

- Due to the **complexity** of these proposed algorithms, still vendors find it unappealing to implement these techniques.

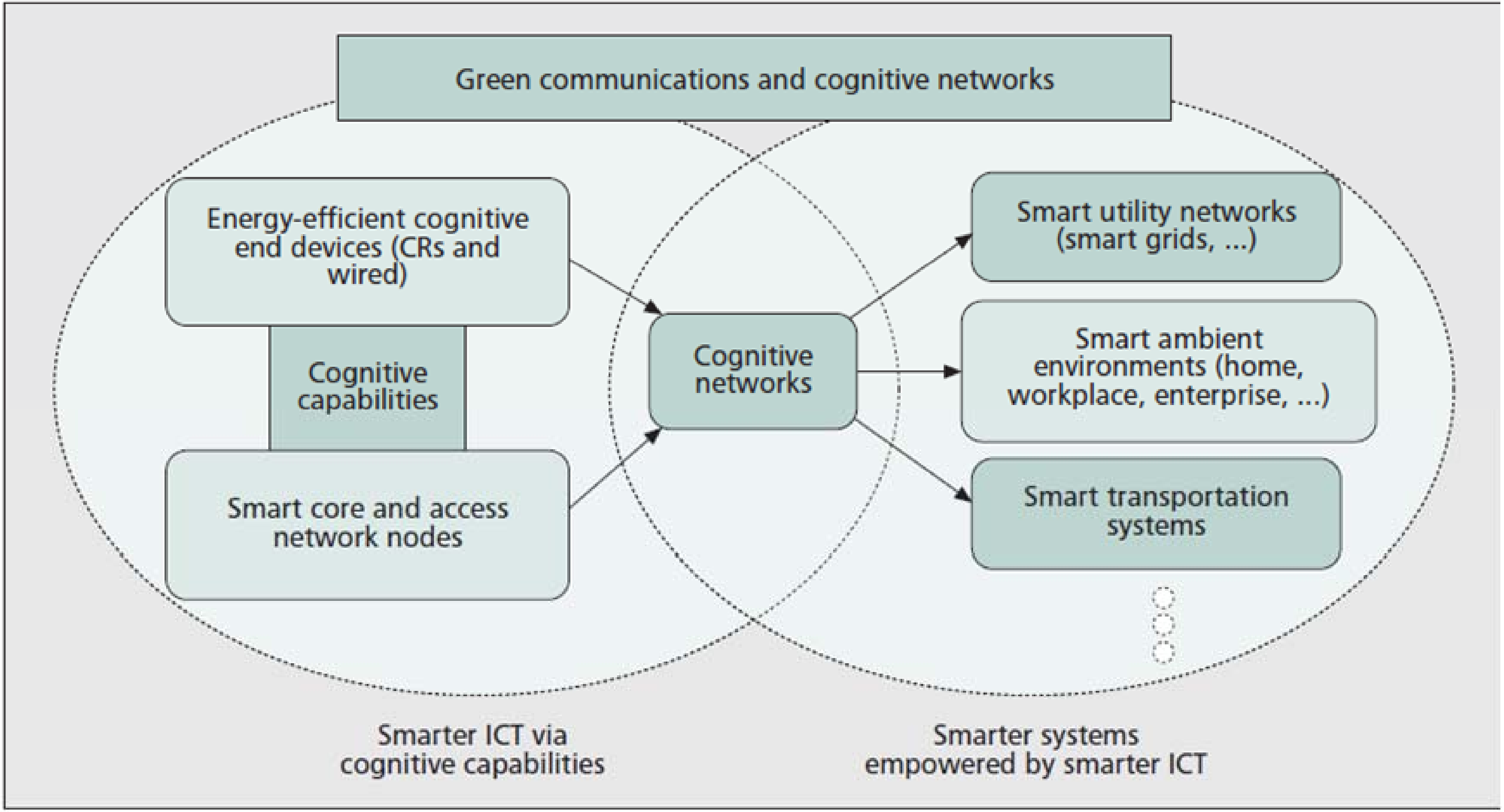
- A **roadway** to future would be striving for more feasible, less complex, and less expensive schemes within the scope of Cognitive Radio.

Benefits of Cognitive Radios for Green Wireless Communications

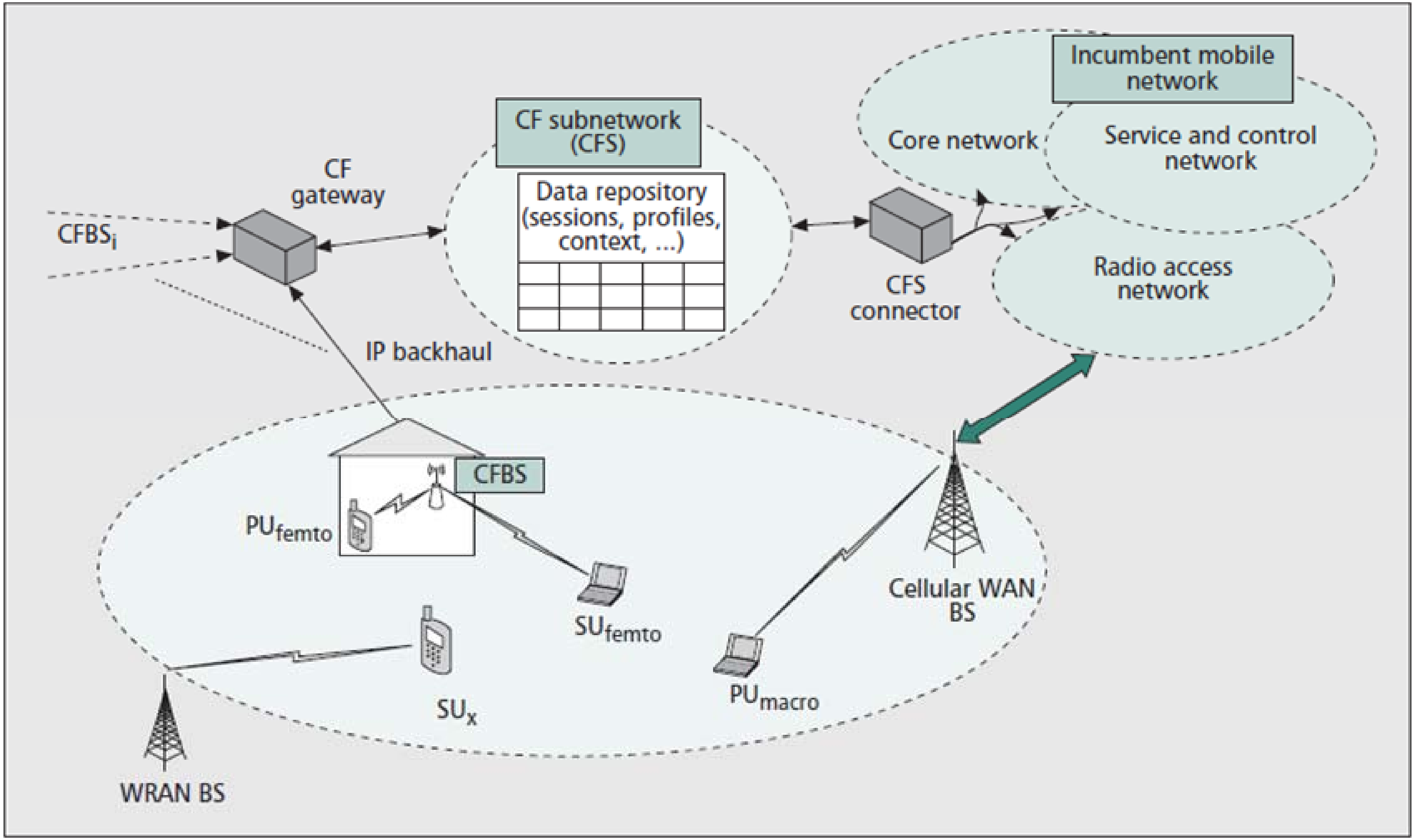
- According to the FCC (FCC NPRM, Dec 17, 2003, ET-03-108), "***A cognitive radio is a radio that can change its transmitter parameters based on interaction with the environment in which it operates***."



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



Cognitive femtocell network



Low-energy spectrum sensing

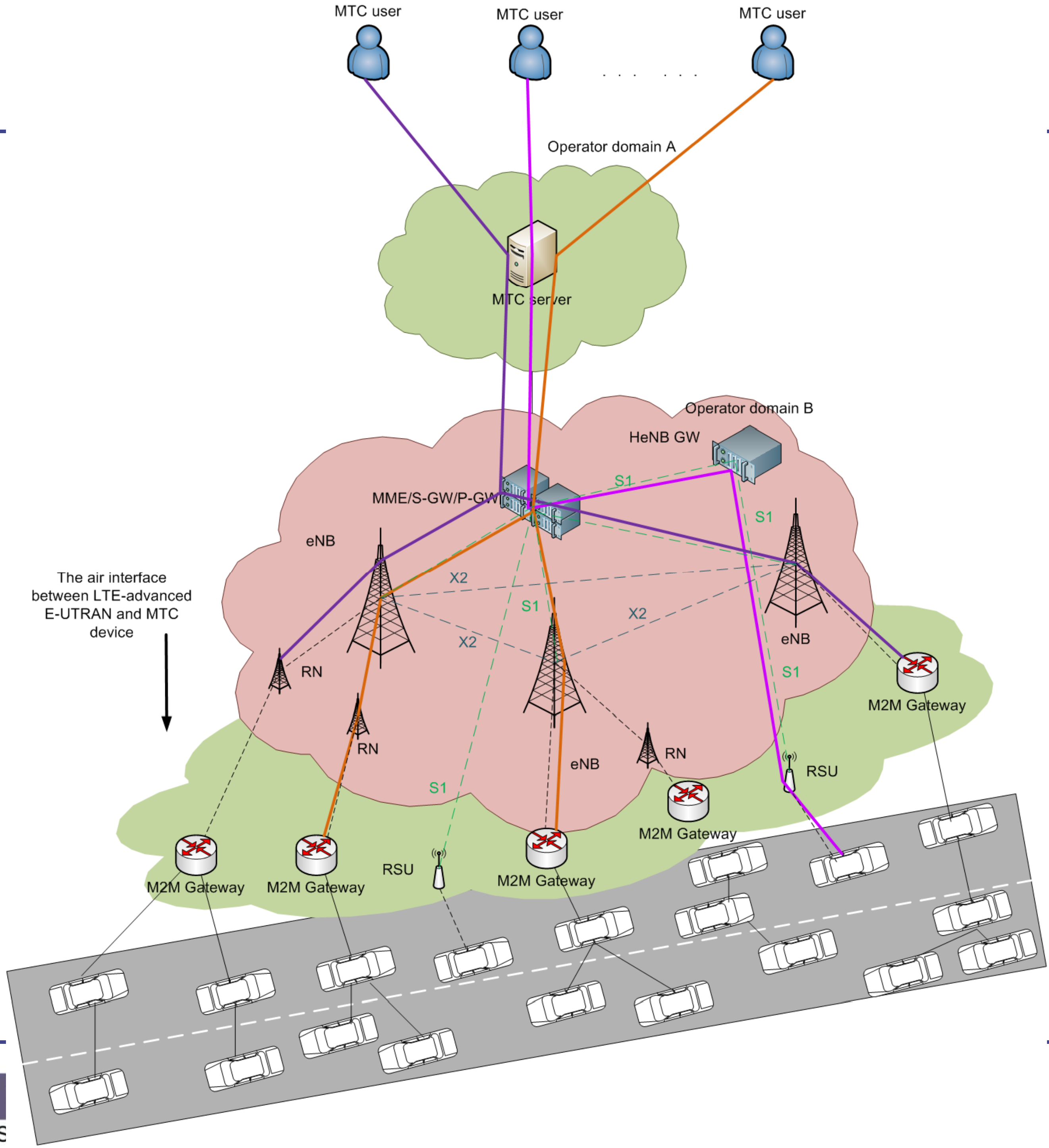
- The use of cognitive radio technology requires frequent sensing of the radio spectrum and processing of the sensor data which would require additional power.
  - They are highly complex and need significant processing power. Therefore, design of **low-complexity** cyclostationary detectors needs to 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

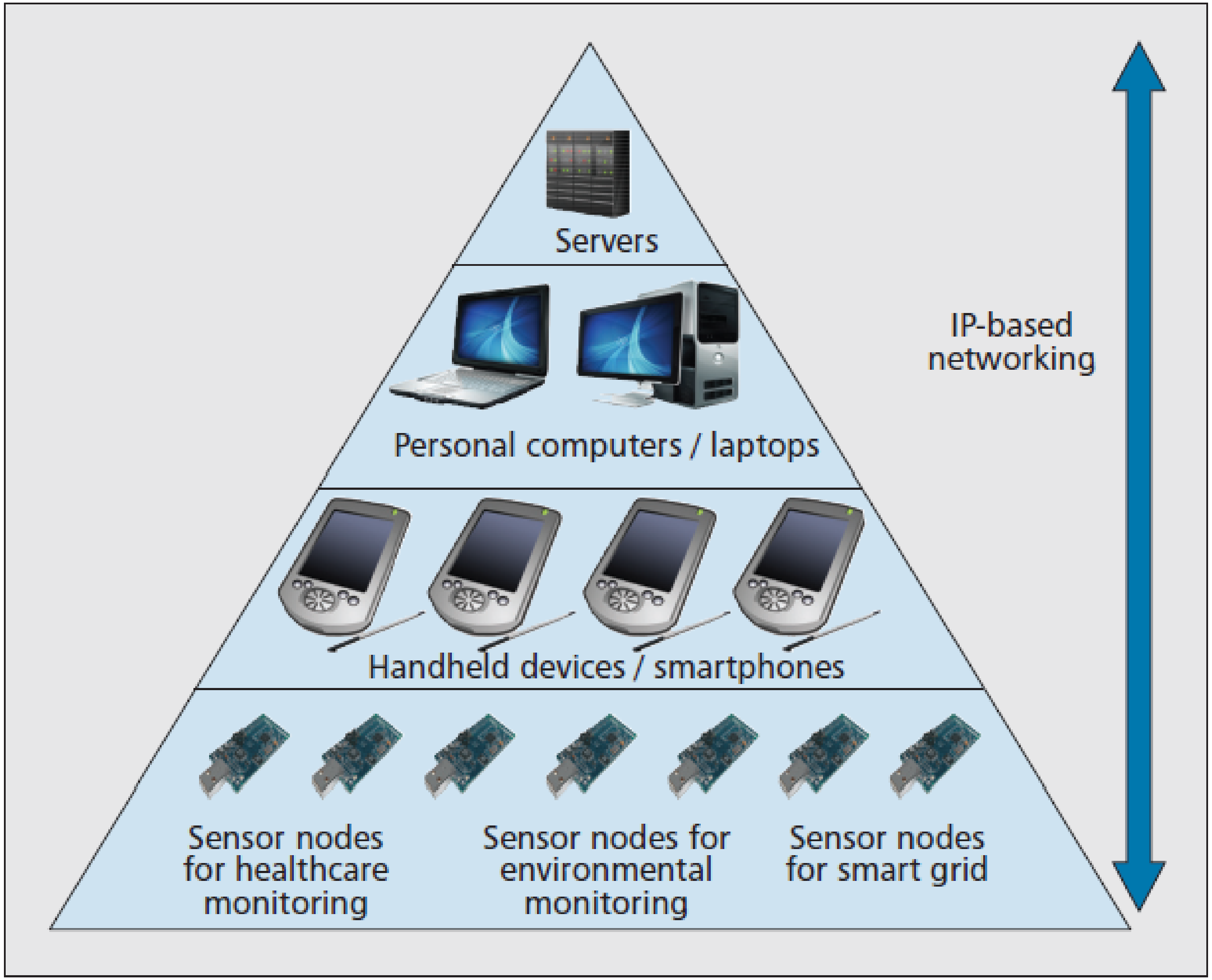
- Most of the research on joint **routing** and **spectrum allocation** does not take into account power efficiency constraints directly.
- Throughput maximization via routing-driven spectrum allocation can be interpreted as power efficiency, since more throughput is achieved using the same amount of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


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

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#2:

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?