GREAT Project Overview

Green Radio Excellence in Architectures & Technologies

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Green Radio Excellence in Arch. & Tech.

HUAWEI TECHNOLOGIES CO., LTD.

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GREAT Project Overview

- **Research Framework**

- **Energy Efficiency Evaluation (3E) Framework**

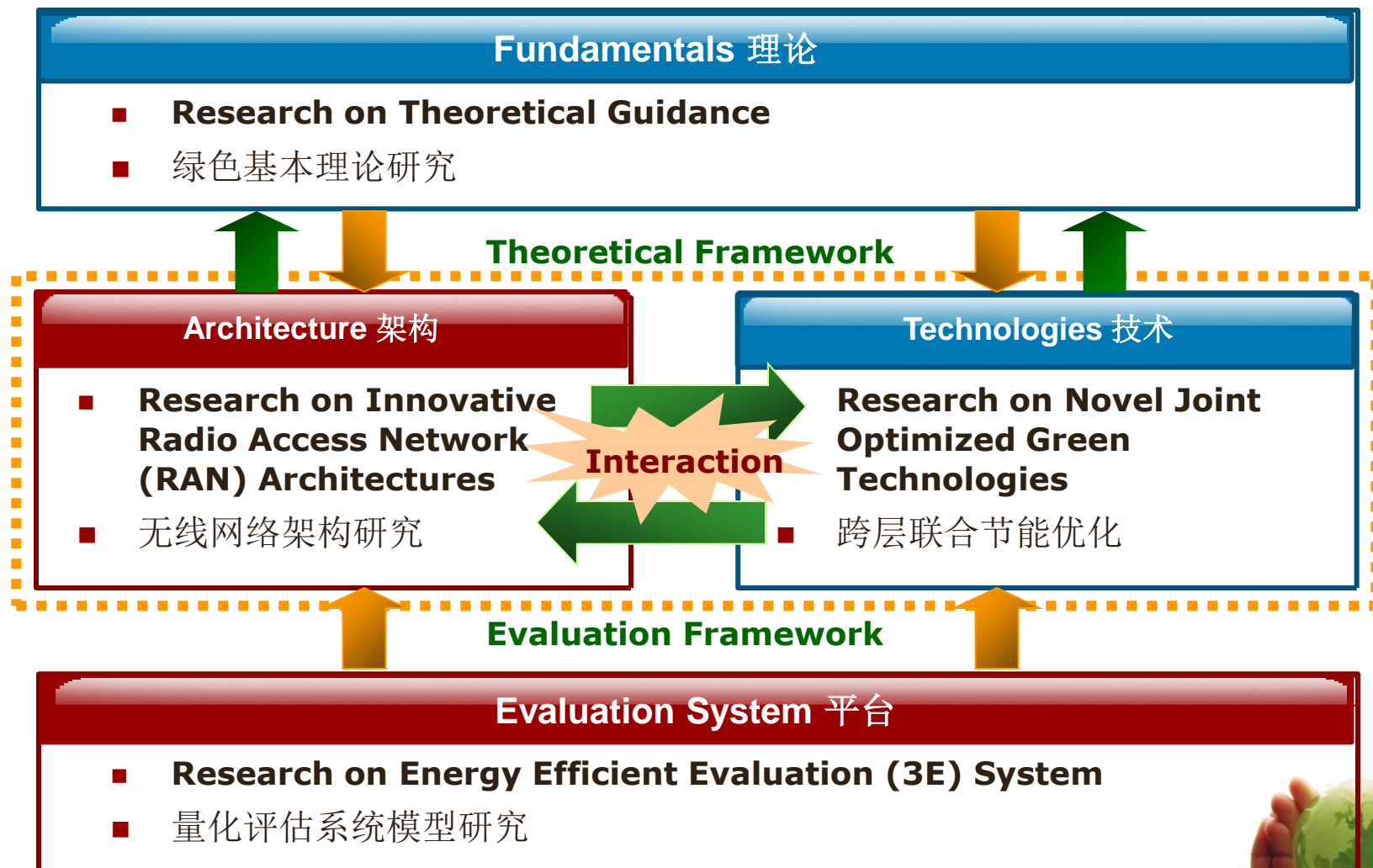- **Fundamental Tradeoffs on Green Design**

GREAT Project Overview

- **Research Framework**
- Energy Efficiency Evaluation (3E) Framework
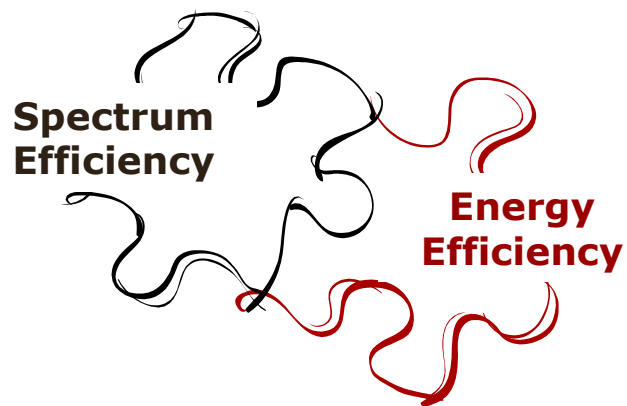- Fundamental Tradeoffs on Green Design

Research Areas – Sandwich Model

Fundamentals 理论

- **Research on Theoretical Guidance**
- 绿色基本理论研究

Theoretical Framework

Architecture 架构

- **Research on Innovative Radio Access Network (RAN) Architectures**
- 无线网络架构研究

Interaction

Technologies 技术

- **Research on Novel Joint Optimized Green Technologies**
- 跨层联合节能优化

Evaluation Framework

Evaluation System 平台

- **Research on Energy Efficient Evaluation (3E) System**
- 量化评估系统模型研究

Research Areas

- **Research on Theoretical Guidance**
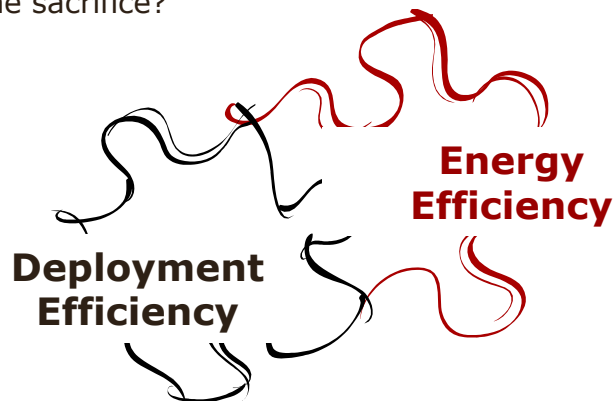
Spectrum Efficiency

Energy Efficiency

SE - EE Tradeoff

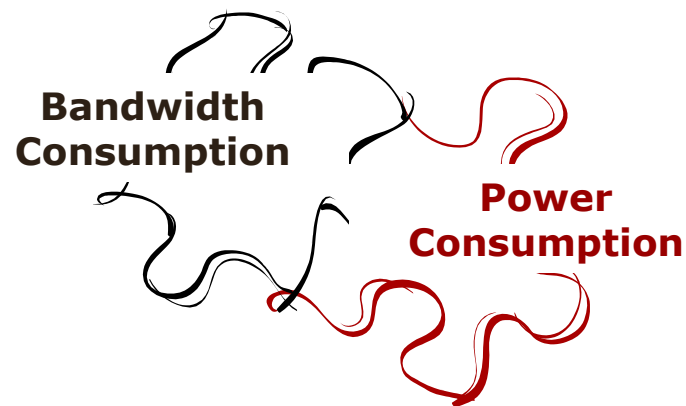Do we need to sacrifice spectrum efficiency for power efficiency? How will the gain vary with the sacrifice?
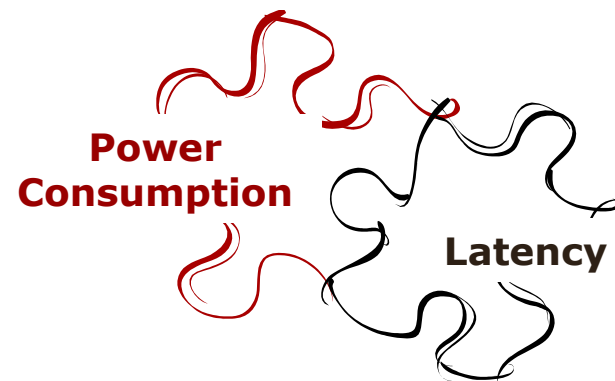
4 Fundamental Tradeoffs

Energy Efficiency

Deployment Efficiency

DE – EE Tradeoff

How much gain can we get in energy efficiency? Does that worth the deployment cost?

Bandwidth Consumption

Power Consumption

Bandwidth - Power Tradeoff

Is that possible to trade aggregated idle bandwidth for power?

Power Consumption

Latency

Power - Delay Tradeoff

How to get balance between QoS (e.g. delay) and power consumption?

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Research Areas

- **Unified Architecture for Energy Efficiency Evaluation (3E)**
  - Define energy efficiency model & metrics for different levels
    - Device/Component Level
    - BTS level
    - Network level
  - Evaluate the gain of different technologies in the framework of energy efficiency
    - CoMP / Relay / Femtocell / DAS …
  - Build unified simulation platform/ testbed for system-level simulation
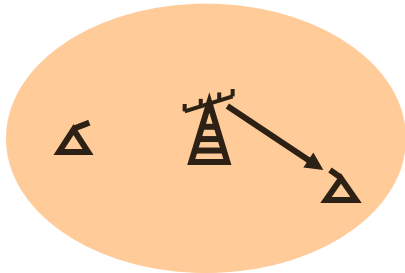   - GSM/ CDMA/ UMTS/ LTE …

Network Level
BTS Level
Device Level

Quantitative Model & Metrics

Unified Evaluation Architecture

CoMP
Relay
Femtocell
DAS
…

Advanced Air Interface Technology

GSM CDMA UMTS LTE ...

System-Level Verifications

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Research Areas

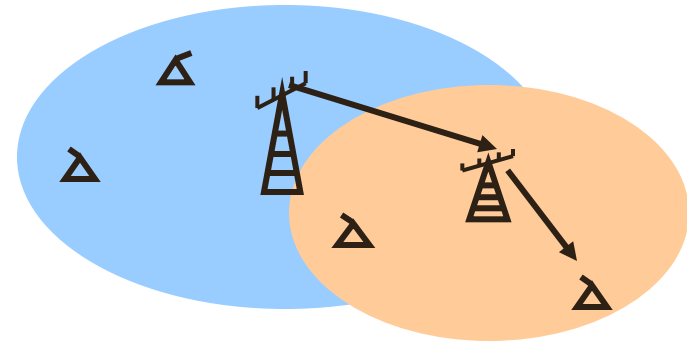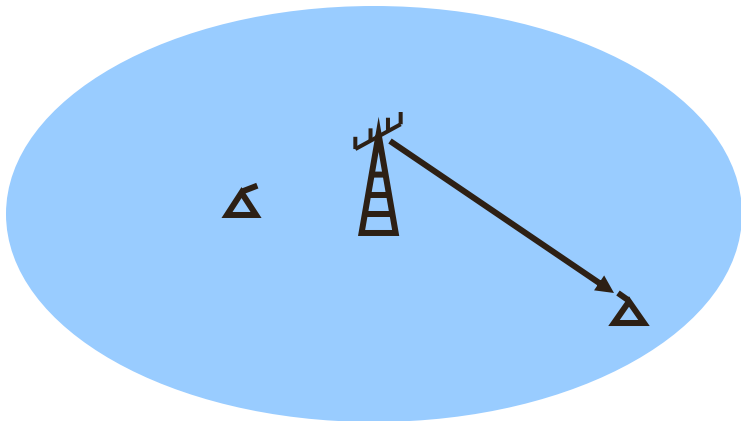**An Example of Deployment Related Study**

- Smaller path-loss
- Smaller Tx Power
- Lower PA Requirement
- More Infrastructure
- CAPEX? OPEX?
- Interference?

Small Cell Size

Relayed Architecture
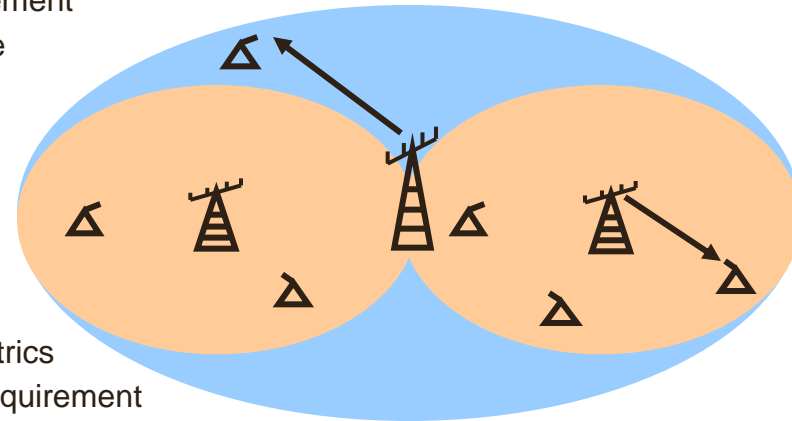
- Largerr path-loss
- Larger Tx Power
- Higher PA Requirement
- Less Infrastructure
- CAPEX? OPEX?
- Interference?

Which Architecture?

Depends on
- Unified Metrics
- Service Requirement
- Site/Equipment Cost
- Dynamic Management

Large Cell Size

Heterogeneous Arch./Multi-RAT

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Research Areas

● **An Example of Relay Study on Optimized Resource Scheduling**

Time slot

Subspace

Power

User

Spectrum
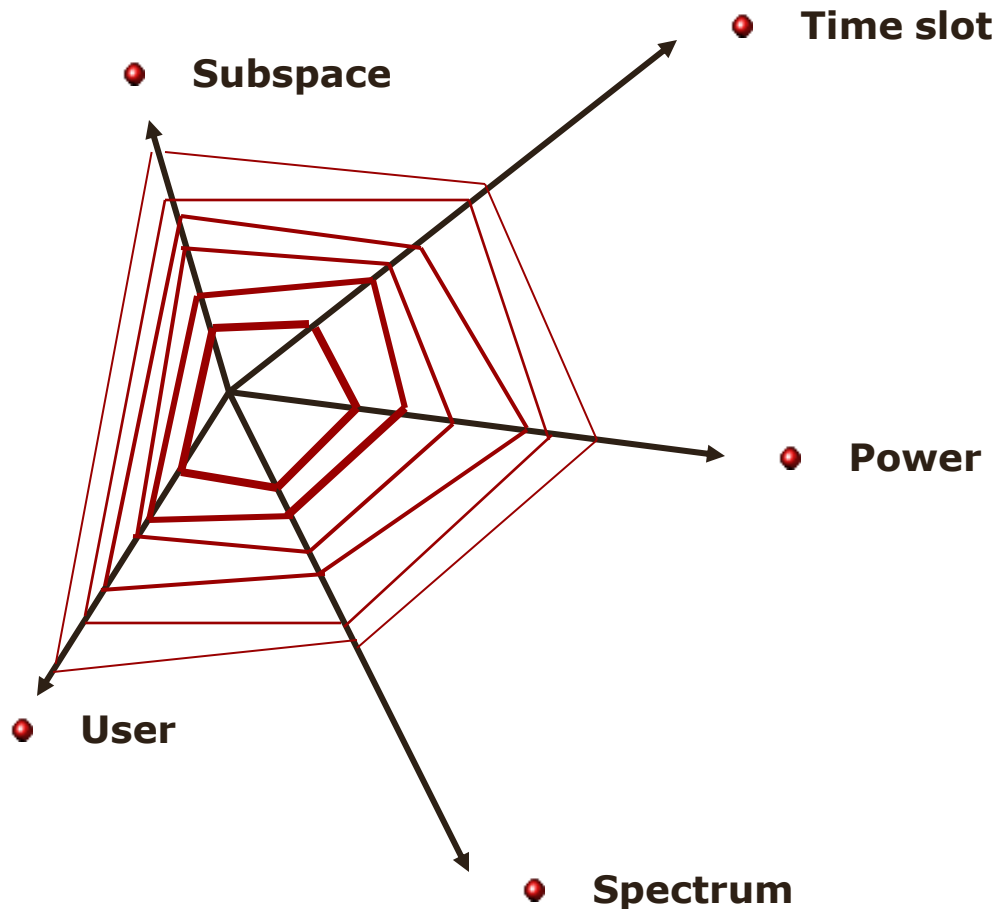
Throughput-Oriented Resource Allocation

Shift to

Energy-Efficiency-Oriented Resource Allocation

How to

Given the QoS requirement, reduce unnecessary energy consumption in any possible way

GREAT Project Overview

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- **Energy Efficiency Evaluation (3E) Framework**
- Fundamental Tradeoffs on Green Design

3E System

Simulation Platform: **Walk with Two Legs**

3E System Construction
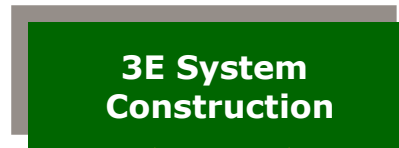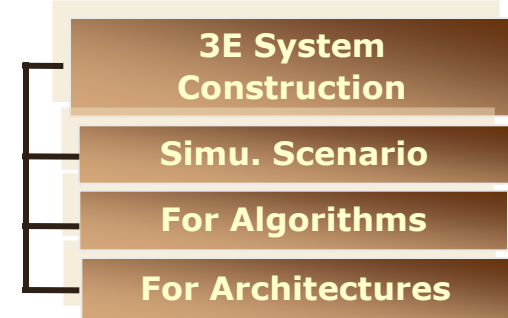
Architecture Evaluation
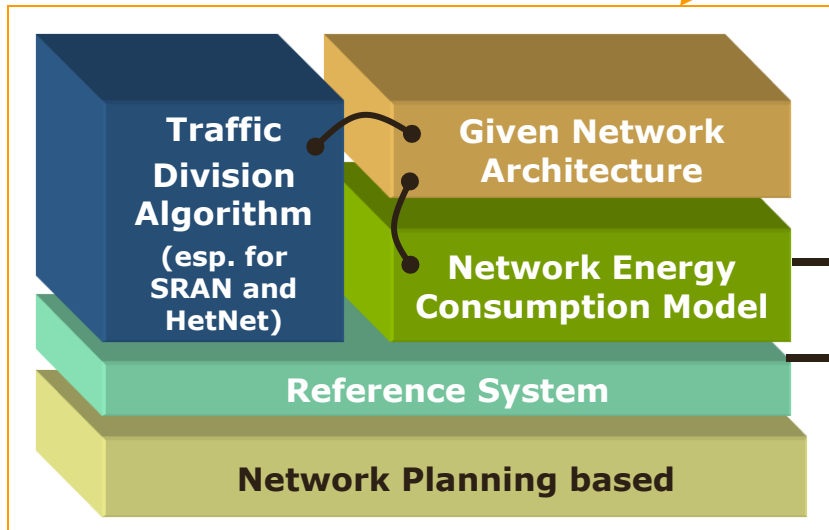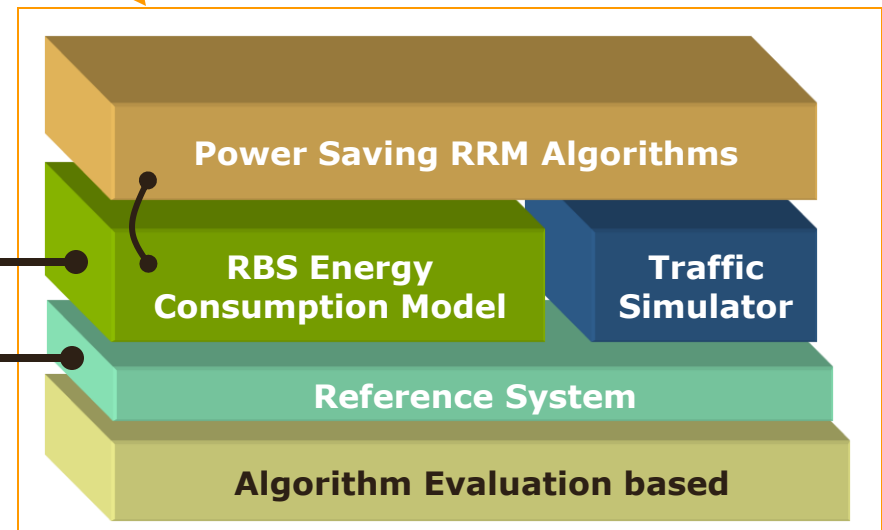
Traffic Division Algorithm (esp. for SRAN and HetNet)

Given Network Architecture

Network Energy Consumption Model

Reference System

Network Planning based

RRM Algorithm Evaluation

Power Saving RRM Algorithms

RBS Energy Consumption Model

Traffic Simulator

Reference System

Algorithm Evaluation based

3E System

Energy Consumption Modeling

Network Level

Network Energy Consumption

Site Level

Site Energy Consumption

RBS Level

RBS Energy Consumption

$P\_net = sum\_i\ P\_site\_i * N\_site\_i$

Which is sum over
•different time period
•Different geographical areas

Huawei is actively coordinating the Wireless Architecture/Metric subgroup in GreenTouch

Air－Conditioner Energy Consumption

RBS Energy Consumption

Cabinet Energy Consumption

Carrier Energy Consumption

Pin = A (conf, traffic, Pout) * Pout + B (conf, traffic, Pout)

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3E System

🔴 **Energy Consumption Modeling**

Carrier Energy Consumption

Dynamic consumption

PA dynamic consumption

Dynamic consumption is closely related to the amount of data traffic

PA static consumption

The PA always has quiescent current to meet raw linearity requirements, which contributes to the static consumption

TRX consumption

Digital IF circuits, AD/DA, small signal RF circuits

TRX

Baseband consumption

Static consumption

Baseband

DSP, FPGA, CPU, and other core devices in baseband processing

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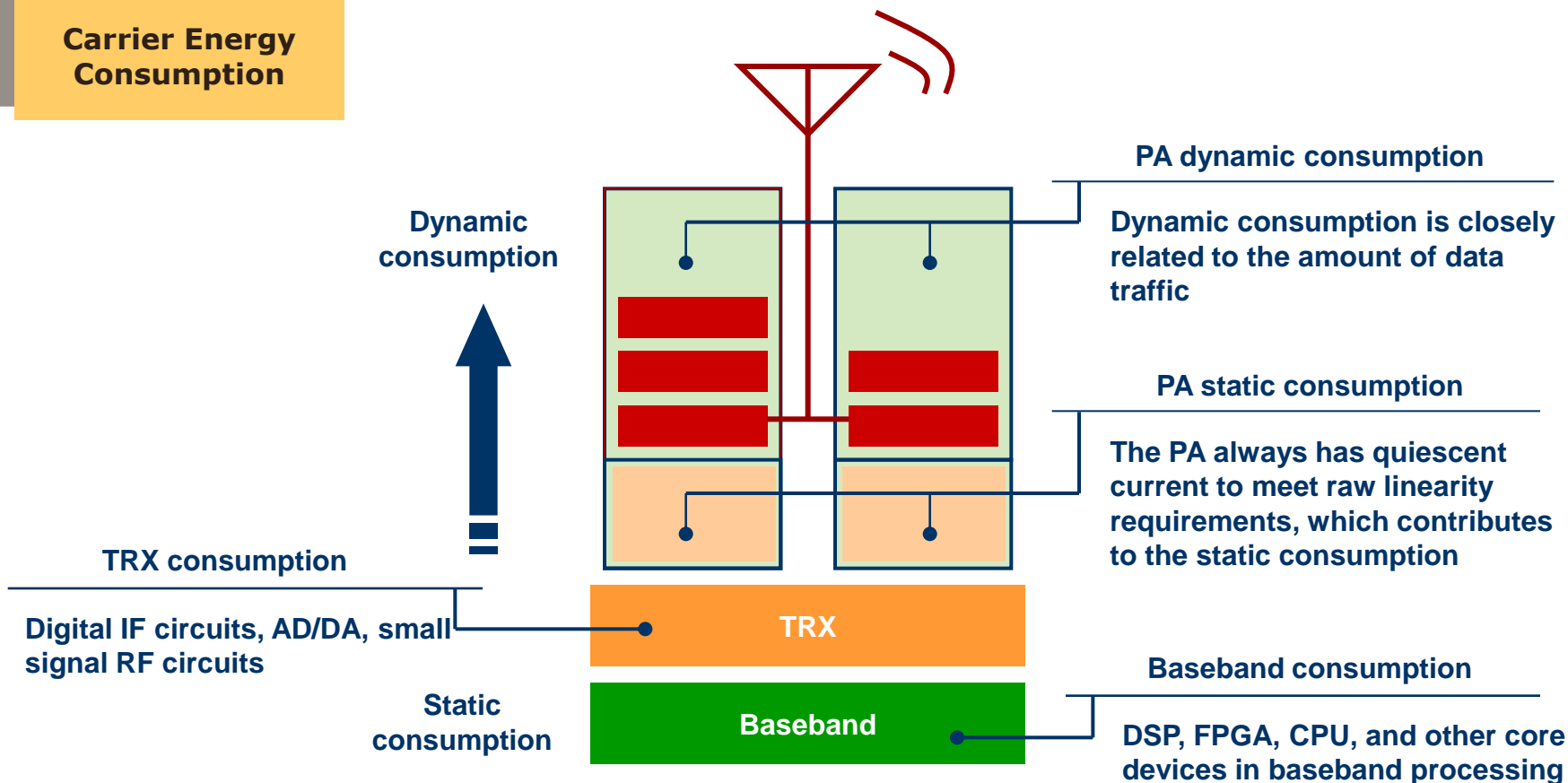
GREAT Project Overview

- Research Framework
- Energy Efficiency Evaluation (3E) Framework
- **Fundamental Tradeoffs on Green Design**

Fundamental Tradeoffs
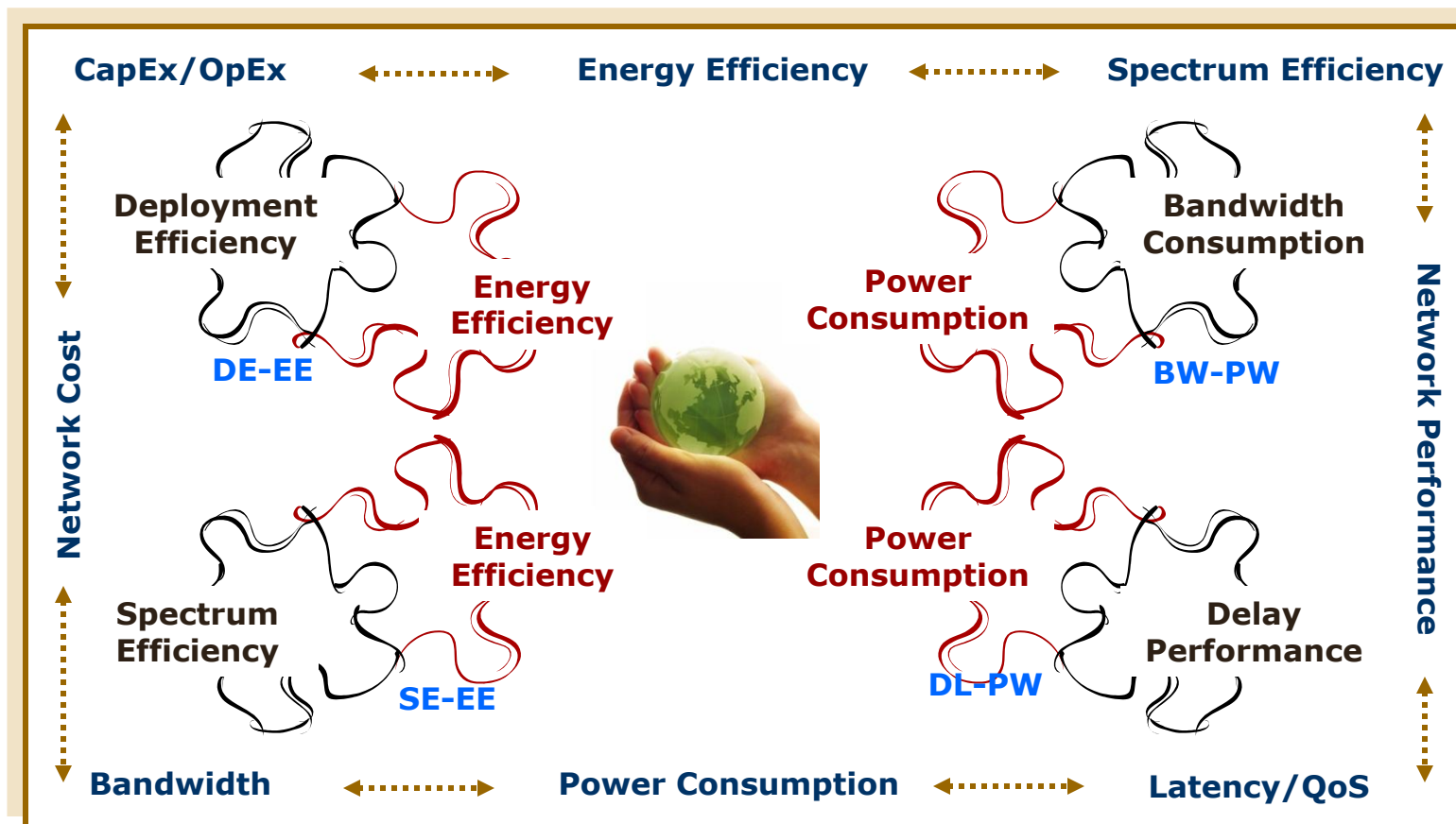
- We identify four fundamental tradeoffs in green wireless network design to improve energy efficiency while guaranteeing satisfactory quality-of-service/ cost

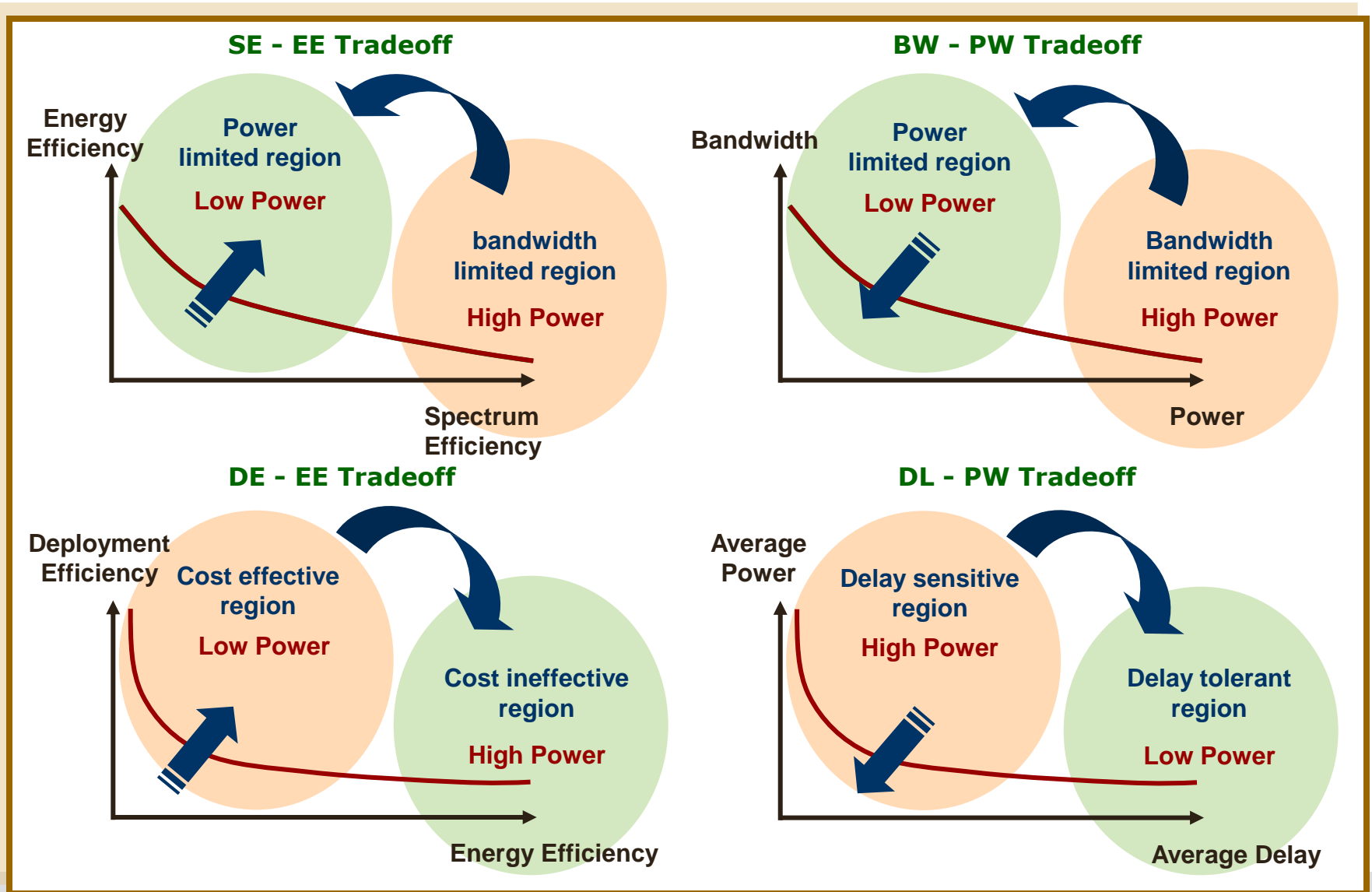- We have got one paper about the four fundamental tradeoffs accepted by IEEE Communications Magazines, http://arxiv.org/abs/1101.4343

Insight from Shannon

SE - EE Tradeoff

Energy Efficiency

Power limited region

Low Power

bandwidth limited region

High Power

Spectrum Efficiency

BW - PW Tradeoff

Bandwidth

Power limited region

Low Power

Bandwidth limited region

High Power

Power

DE - EE Tradeoff

Deployment Efficiency

Cost effective region

Low Power

Cost ineffective region

High Power

Energy Efficiency

DL - PW Tradeoff

Average Power

Delay sensitive region

High Power

Delay tolerant region

Low Power

Average Delay

Leading GTT Project in GreenTouch

SE-EE Tradeoff

Energy Efficiency (bits/Joule)

Power limited region

Low Power

bandwidth limited region

High Power

Spectrum Efficiency (bps/Hz)

DL - PW Tradeoff

Average Power (Watt)

Delay sensitive region

High Power

Delay tolerant region

Low Power

Average Delay (sec)
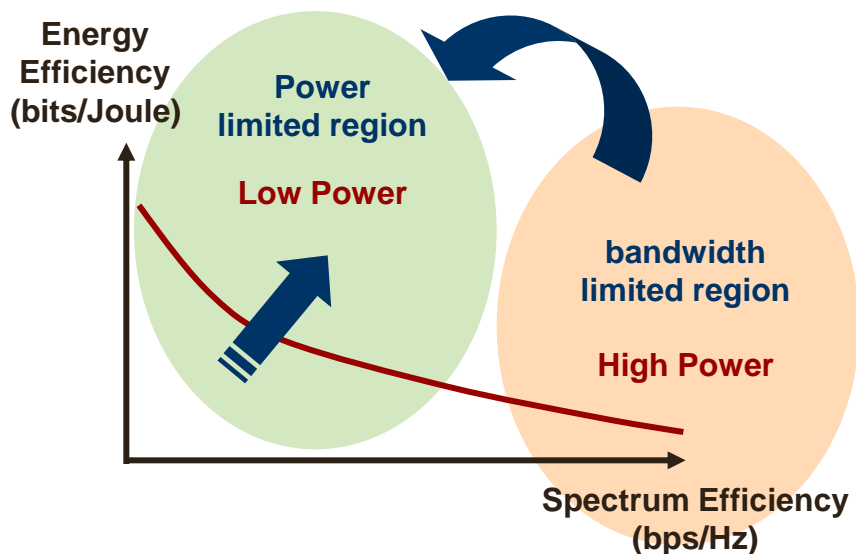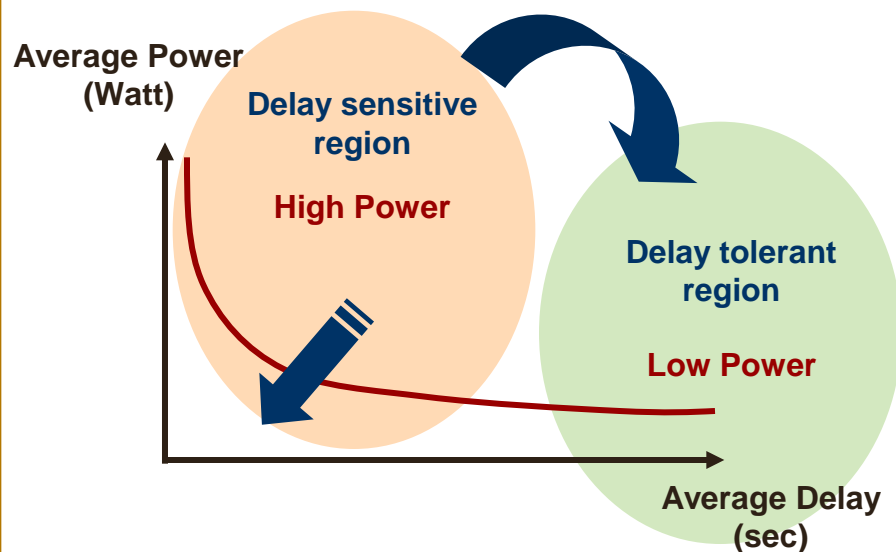
- **Expanding** the channel bandwidth at given rate requirement (i.e., trading bandwidth for power) ;

- **Reducing** the transmission rate at given bandwidth (i.e. trading rate for power)

- **Developing** novel radio transmission technologies and architectures to push the tradeoff curve outwards (i.e. improving spectrum efficiency and energy efficiency simultaneously).

- **Prolonging** the service/transmission time but without deviating the user's QoS requirement by developing novel resource management and scheduling algorithms (i.e., trading delay for power) ;

- **Developing** novel radio transmission technologies and architectures to make the service more efficient (i.e. reducing energy consumption and reducing delay simultaneously).
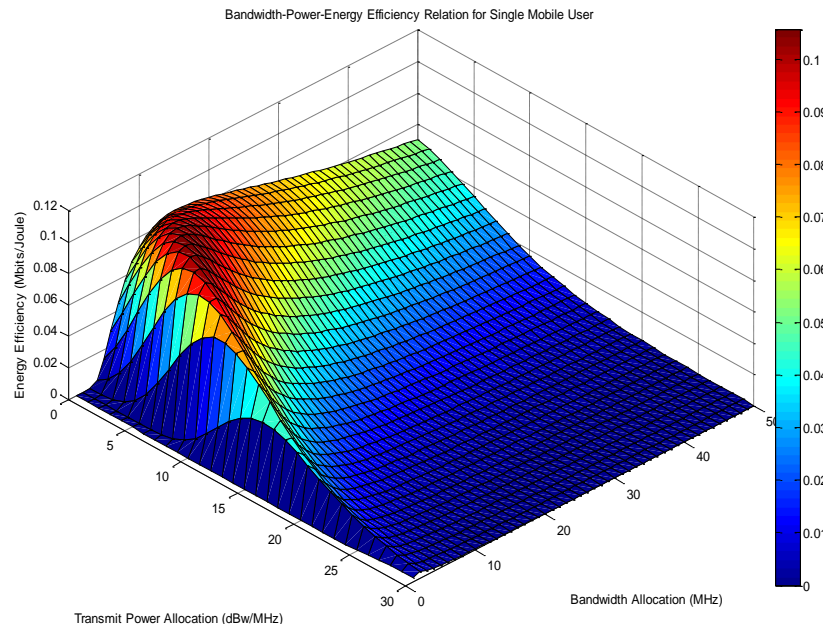
However, in Practice

**Example of DE-EE Curves
under practical constraints**

**Example of BW-PW-EE Curves
under practical constraints**

Bandwidth-Power-Energy Efficiency Relation for Single Mobile User
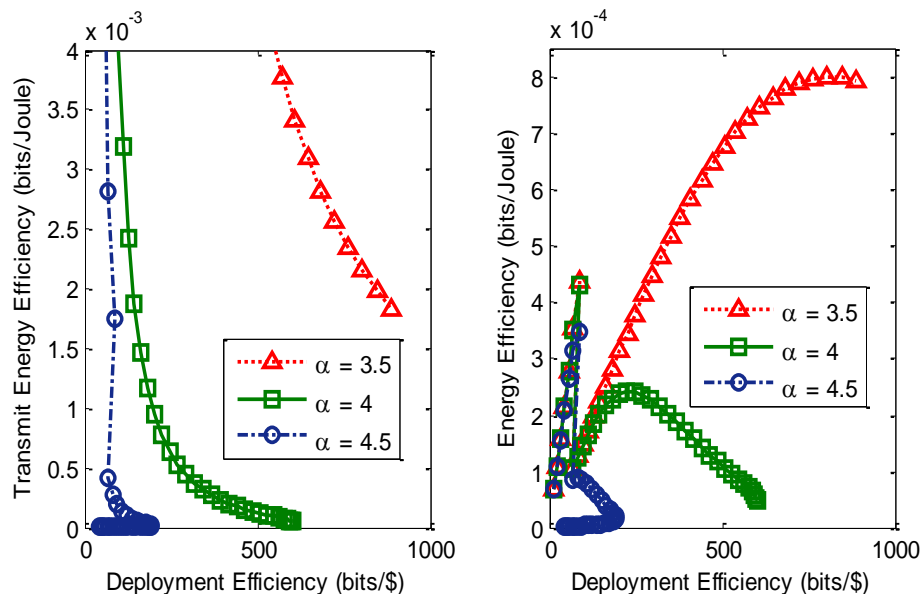
- **Only Tx power considered, the tradeoff curve matches our intuition**
- **Static power and circuit power also considered, the tradeoff curve deviates our intuition**
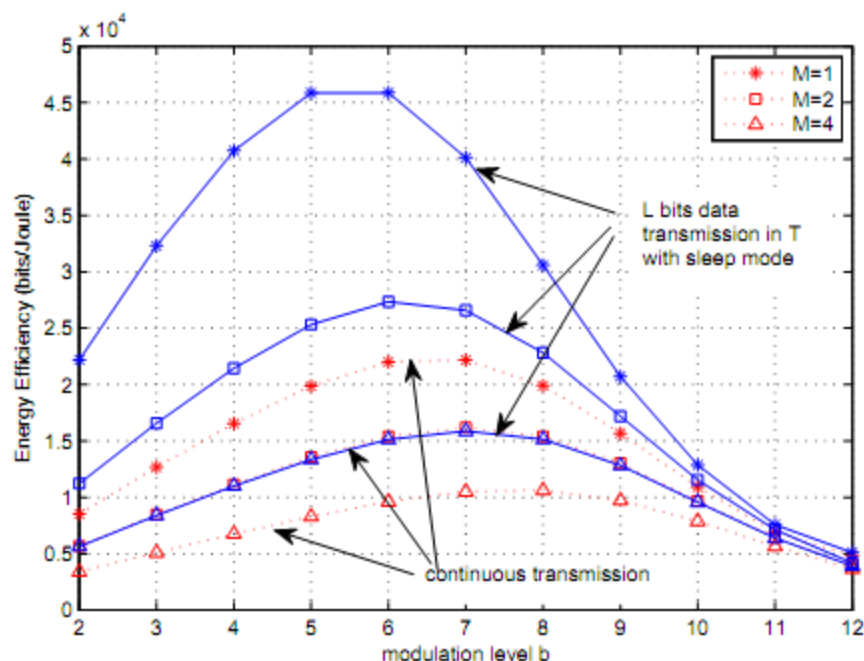- **Be careful when embracing smaller cells**

- **Full utilization of bandwidth-power resource may not be most energy efficient**
- **Given target EE, the BW-PW tradeoff relation is not monotonic**

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However, in Practice

Example of DE-EE Curves under practical constraints

Example of SE-EE Tradeoff in single relay system under practice constraints

- The SE-EE curve under practical power model is no longer monotonic
- Sleep mode helps reduce circuit power
- Given the traditional way of RF architecture, increasing antenna does not always help increase EE
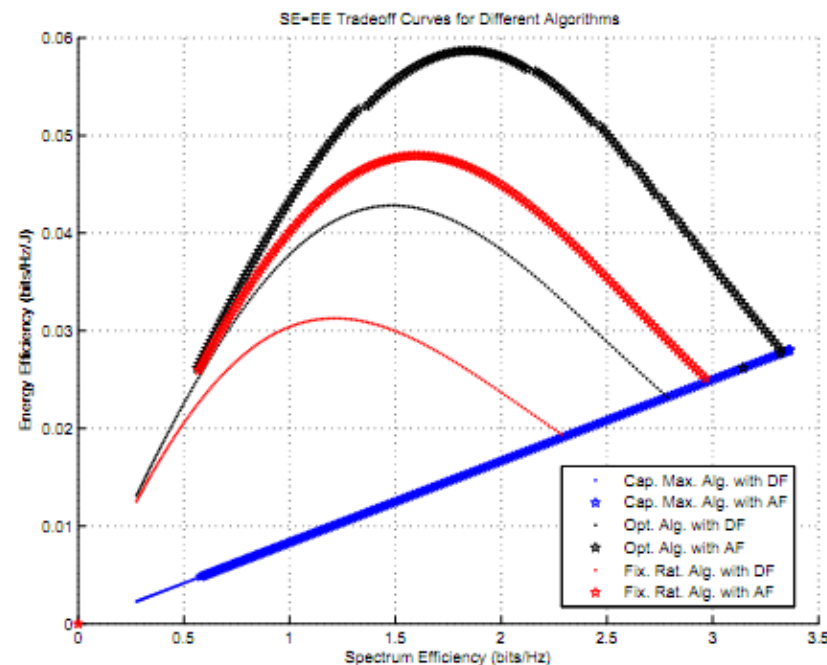
- When circuit power for both source and relay are considered, the SE-EE curve is no longer monotonic
- Optimized resource allocation between source and relay always helps increase EE

Reference

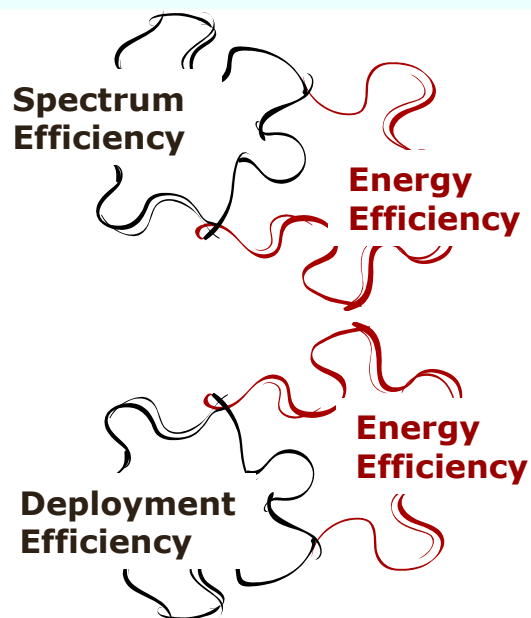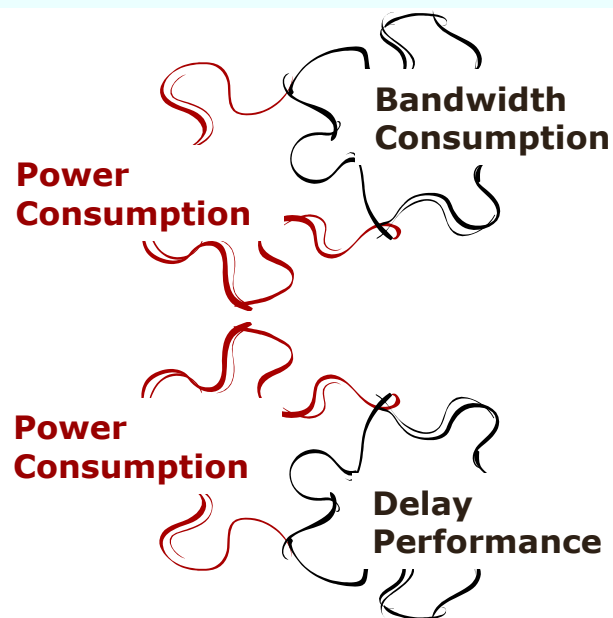- Shunqing Zhang, Yan Chen, and Shugong Xu, ", Energy Efficient Resources Allocation for Relay-Assisted Networks," **in Proc. WWRF**, Penang, Malaysia, Apr 2010.

- Yan Chen, Shunqing Zhang, and Shugong Xu, "Impact of Non-ideal Efficiency on Bits per Joule Performance of Base Station Transmissions," **in Proc. IEEE VTC Spring**, Budapest, Hungry, June 2011.

- Shunqing Zhang, Yan Chen, and Shugong Xu, ", Improving Energy Efficiency through Bandwidth, Power, and Adaptive Modulation," **in Proc. IEEE VTC fall**, Ottawa, Canada, Sept 2010.

- Shunqing Zhang, Yan Chen and Shugong Xu, "Joint Bandwidth-Power Allocation for Energy Efficient Transmission in Multi-user Systems," **in Proc. IEEE Globecom**, Miami, Florida, USA, Nov 2010.

Spectrum Efficiency

Energy Efficiency

Energy Efficiency

Deployment Efficiency

- Yan Chen, Shunqing Zhang, Shugong Xu, and Geoffrey Ye Li, "Fundamental Tradeoffs on Green Wireless Networks," to appear in **IEEE Communications Magazines**, Special Issue on Green Communications, 2010.

Power Consumption

Bandwidth Consumption

Power Consumption

Delay Performance

- Yan Chen, Shunqing Zhang, and Shugong Xu, "Characterizing Energy Efficiency and Deployment Efficiency Relations for Green Architecture Design," **in Proc. IEEE ICC E2NET Workshop**, Cape Town, South Africa, May 2010.

- Yan Chen, Shunqing Zhang, and Shugong Xu, "Improving Power-Delay Tradeoff via Traffic-Based Adaptive Modulation Scheme under Practical Power Consumption Model," **submitted to IEEE ICC**, Kyoto, Japan, June 2011.

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Fundamental Framework
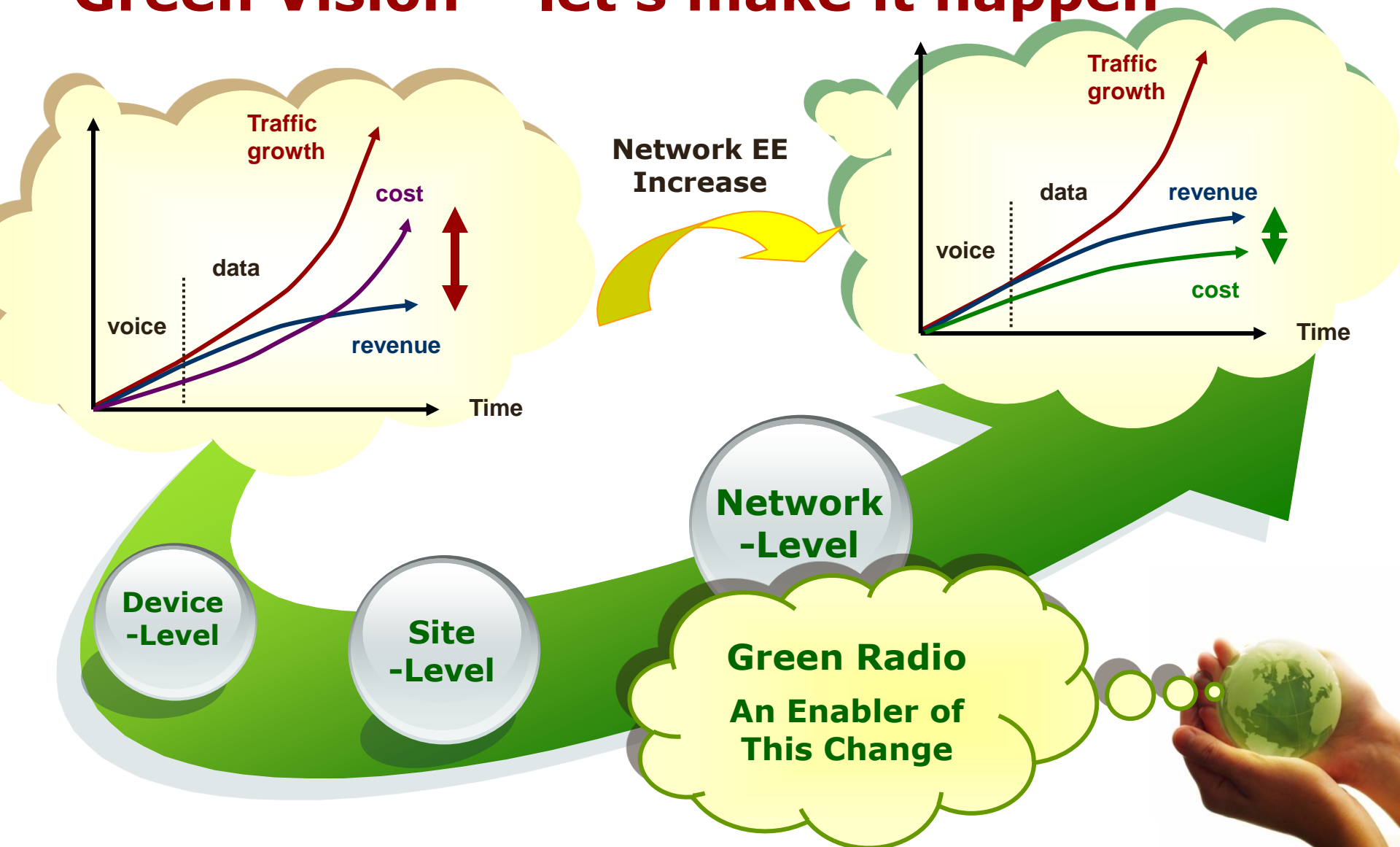

Design Guidance

- Theoretical Limits & Achievable Regions
- Gaps between boundaries and practical systems
- Directions for EE improvement

BW - PW Tradeoff

DL - PW Tradeoff

SE - EE Tradeoff

DE - EE Tradeoff

Green PHY Techniques

- Interference Management Techniques
- SDR-based Techniques
- Smart Antenna Techniques

Joint design

Green Resource Management

Subspace
Time slot
Power
Spectrum
User

Throughput-Oriented Resource Allocation

Shift to

EE-Oriented Resource Management

macro

pico/femto
relay
remote radio head

Green Network Planning

- Network architecture design
- Cell size optimization
- Dynamic Cooperation & Management

- **Huawei is currently leading the GreenTouch project – Green Transmission Technologies (GTT), which is based on the fundamental tradeoffs**

Green Vision – let's make it happen

Traffic growth
cost
data
voice
revenue
Time

Network EE Increase

Traffic growth
data
revenue
voice
cost
Time

Network -Level

Device -Level

Site -Level

Green Radio

An Enabler of This Change

Thank You!