UK-China Science Bridge Project

Thinking on Future Wireless Communications

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Background

Wireless Everywhere

Voice

SMS

Mobile TV

Wireless Internet

Social Networking

You Tube

Email

WiFi

Yesterday- 15 years ago
Millions of wireless devices

Today
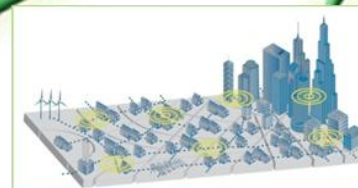**Billions of** wireless devices

Background

Wireless Everywhere

Cyber Physical Systems

Internet of Things

Environment

New Devices

Health Care

Energy

People to People	⇒	People to machines	⇒	Machines to Machines

Tomorrow +15 years   **Trillions** of Wireless devices

The Major Application Trends

EMS

ILS

Smart Grid

Mobile Internet of Things

ITS

Green Buildings

Smart Home
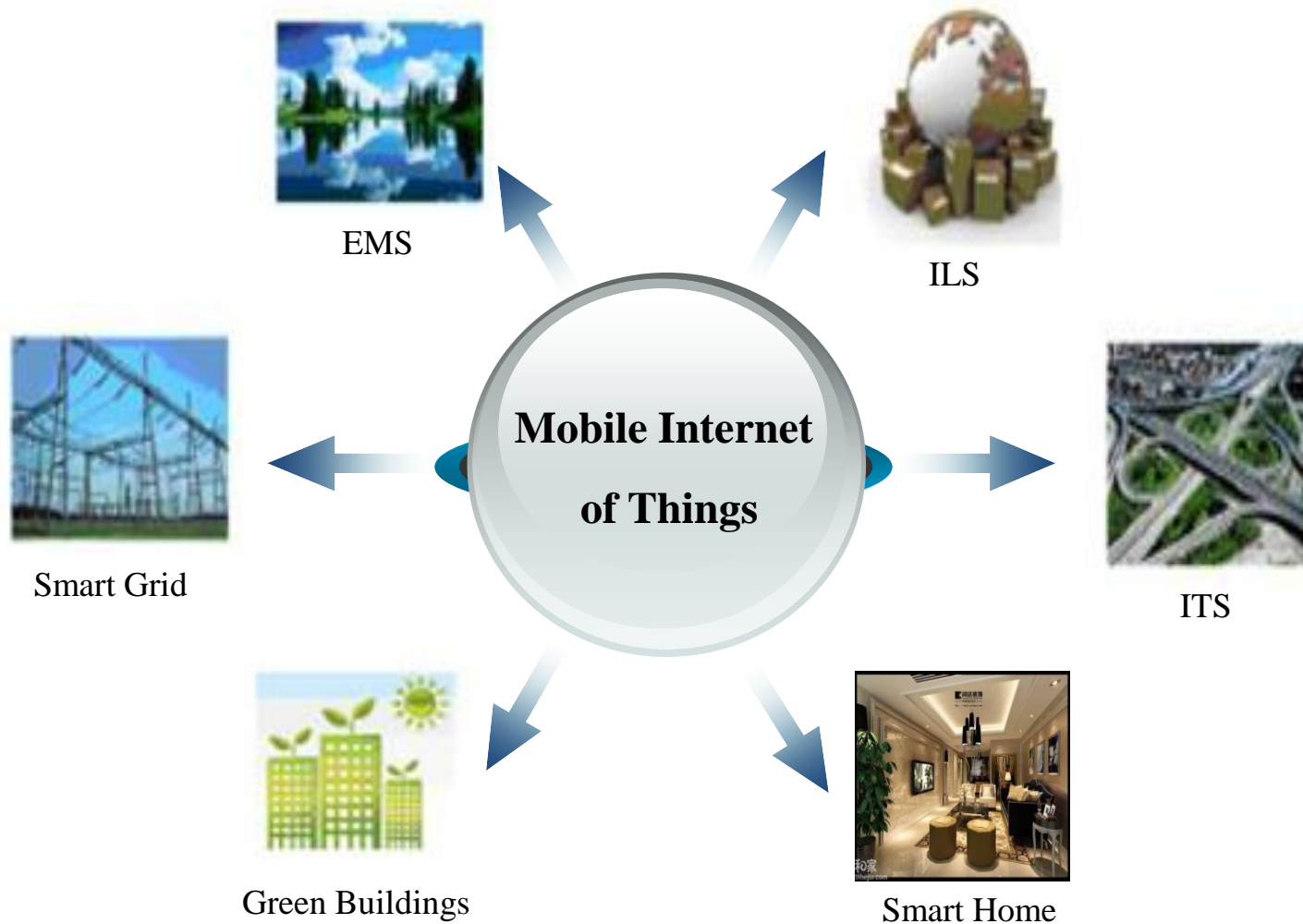
Overall Challenges
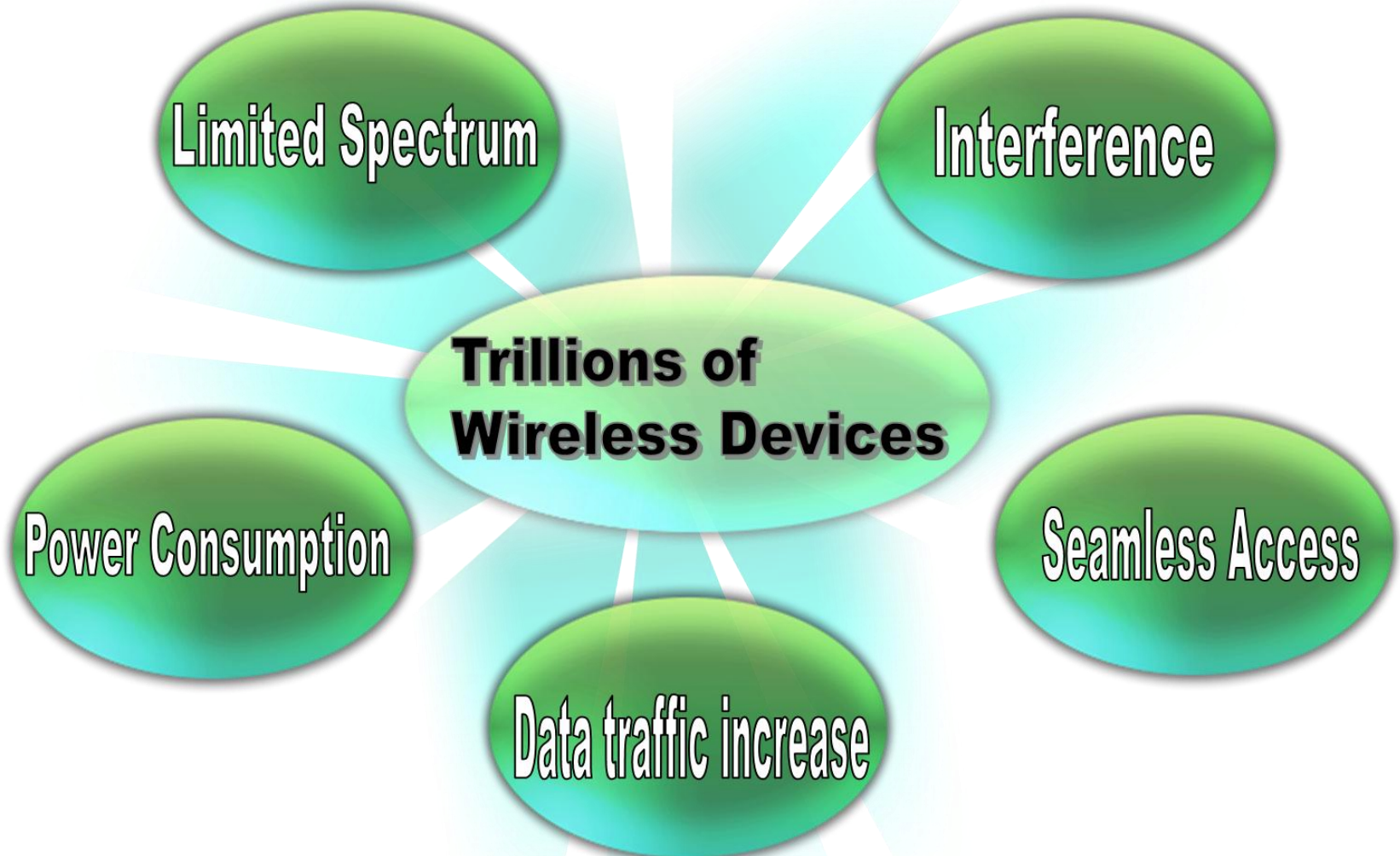
Challenges: A Technical Eye

□ **Is Physical Layer Dead?**

- ✓ **Overall objective:** Tradeoff between spectrum efficiency and energy efficiency

- ✓ **Where we are:** Shannon limit has already been achieved (Turbo/LDPC/MIMO/OFDM)

- ✓ **Road Ahead:**

  - ● From link optimization to network (system) optimization

  - ● From spectrum optimization to joint spectrum and energy optimization

Challenges: A Technical Eye

❑ **Beyond Shannon**

Use higher power
Cooperation, relay, multi-hop, physical network coding

$$C = \sum_{Channels} B_i \log_2(1 + P_i / N)$$

Use more channels
MIMO
IA(Interference Alignment)
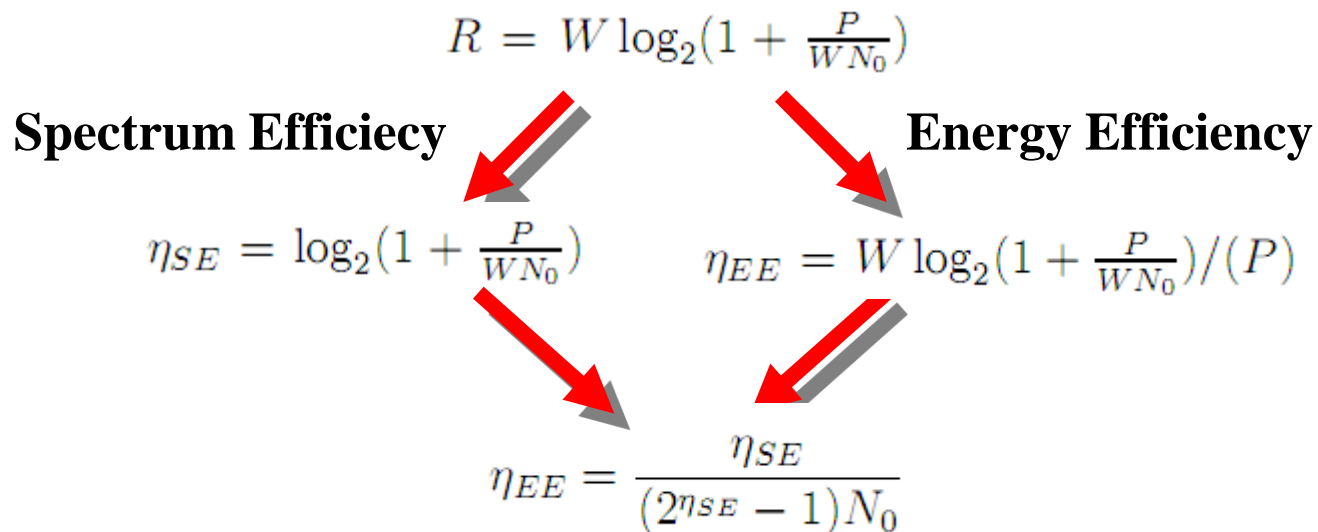*Co-MIMO/CoMP/SM*

Use wider bandwidth
Cognitive Radio
UWB

Challenges: A Technical Eye

❑ **Beyond Shannon**

- Joint optimization of spectrum, energy, and QoS (delay, rate, cost, etc.)
- E.g., for Point-to-point link

$$R = W \log_2(1 + \frac{P}{WN_0})$$

Spectrum Efficiecy

Energy Efficiency

$$\eta_{SE} = \log_2(1 + \frac{P}{WN_0})$$

$$\eta_{EE} = W \log_2(1 + \frac{P}{WN_0})/(P)$$

$$\eta_{EE} = \frac{\eta_{SE}}{(2^{\eta_{SE}} - 1)N_0}$$

- More considerations in practical: hardware cost, network topology, resource optimization

How to solve?

VANET

Data blowout

WSN

Wireless Mesh

WBAN

Requirement increases

WiMAX

Smart home

challenges

Limited spectrum

Power consumption

How to solve?

…
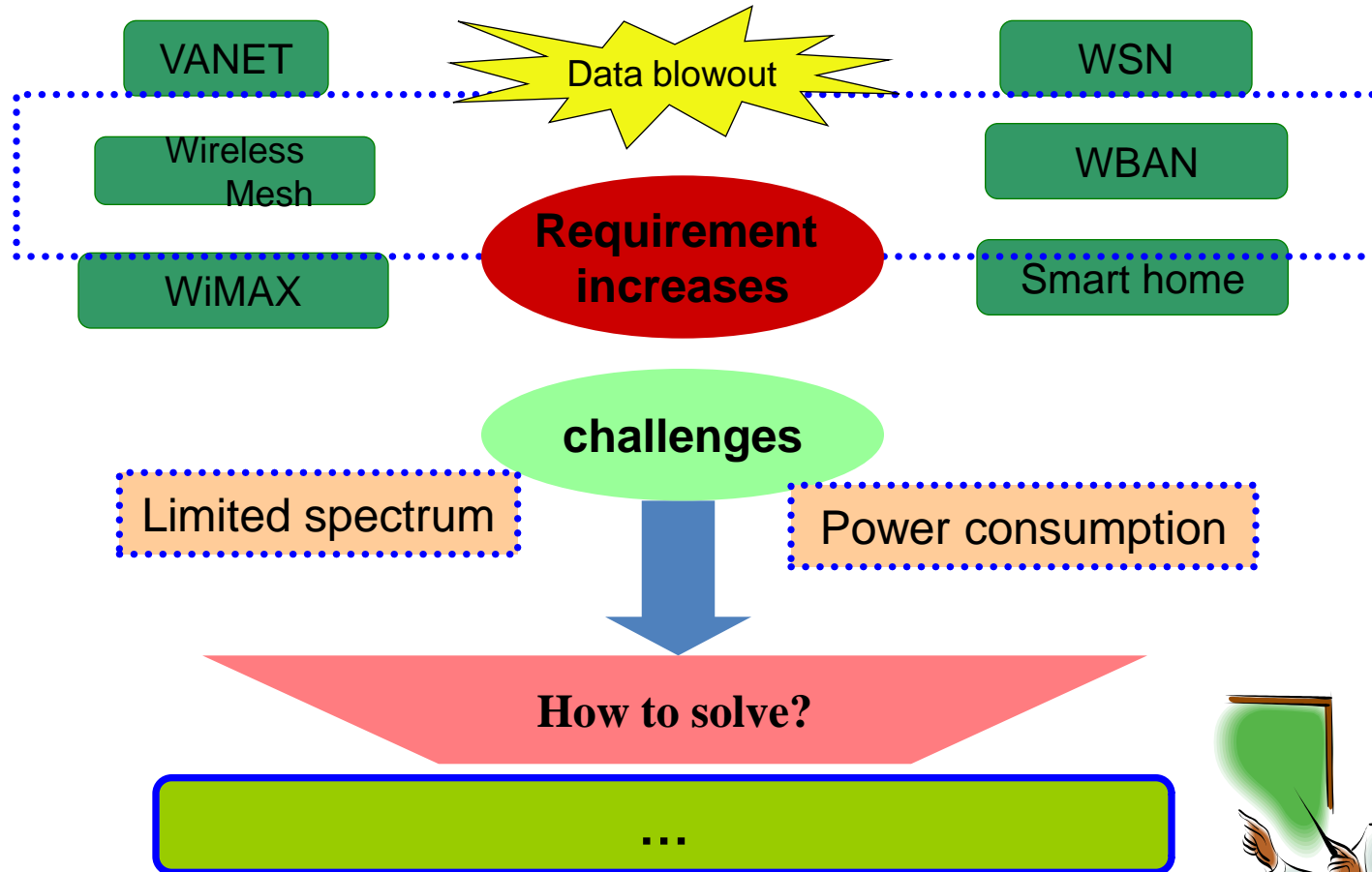
Future Directions

❑ **Network Information and Key Technology**

❑ **Green Communication by Environment Sensing**

❑ **Resource Optimization by Cross-layer Design**

❑ **Rethink of Interference Management**

❑ **Emerging Applications**

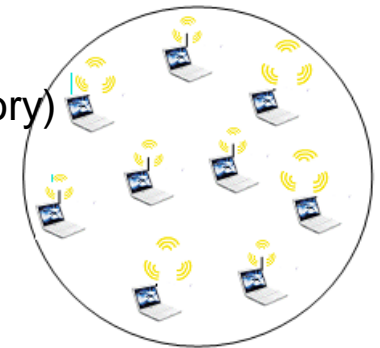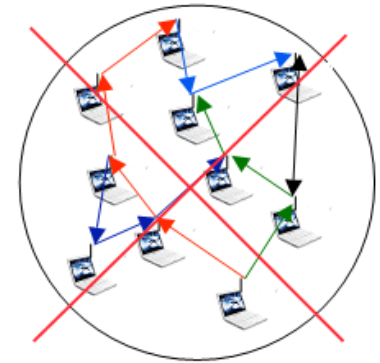# Network Information and Key Technology

□ **Classic information theory**

   ✓ Focuses on capacity of point-to-point link

   ✓ Shannon information theory

□ **Road ahead: network information theory**

   ✓ Focuses on capacity of the whole network

   ✓ Shannon information theory plus network information theory

   ✓ E.g., Graph theory, topology theory, scheduling, optimization, statistical theory

□ **Open problems and key technologies**

   ✓ Analysis of network capacity (e.g., using scaling law)

   ✓ Effects of mobility in wireless networks (e.g., statistical theory)

   ✓ Key technologies: relay, cooperation, network coding, etc.

Network Information and Key Technology

Commun. Theory

Optimization Theory

Network Information Theory

Game Theory

Info. Theory

Quite different with present

Future Network

?

Wireless and optical based

[The NSF FIND Program](#)
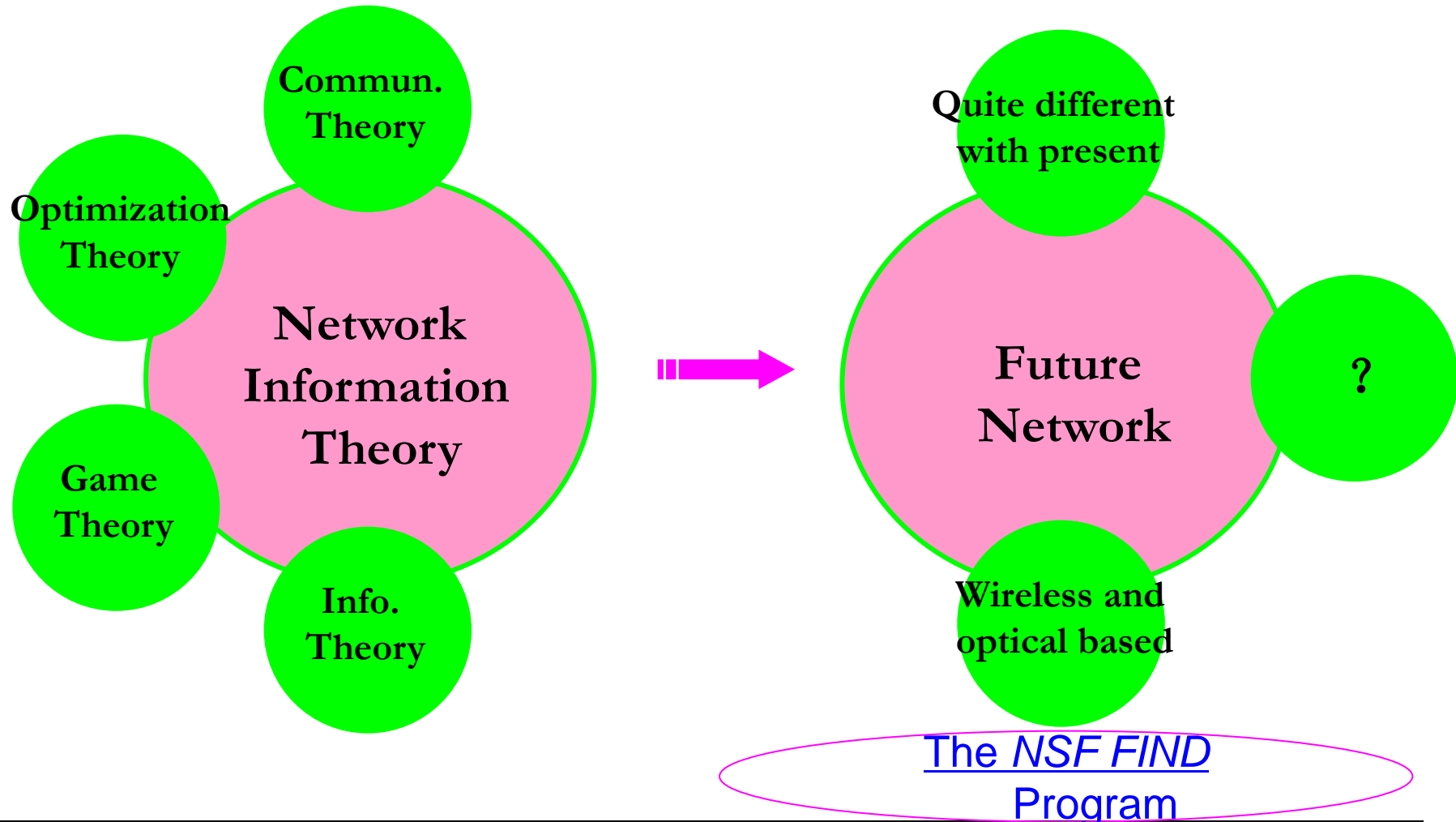
Green Communication by Environment Sensing

❑ **Conventional**

- ✓ QoS maximization supposing radio resource is sufficient
- ✓ Emphasizing performance of single end-user

❑ **Road ahead**

- ✓ Radio resource (spectrum, energy, etc.) is limited
- ✓ Save energy → Green communication

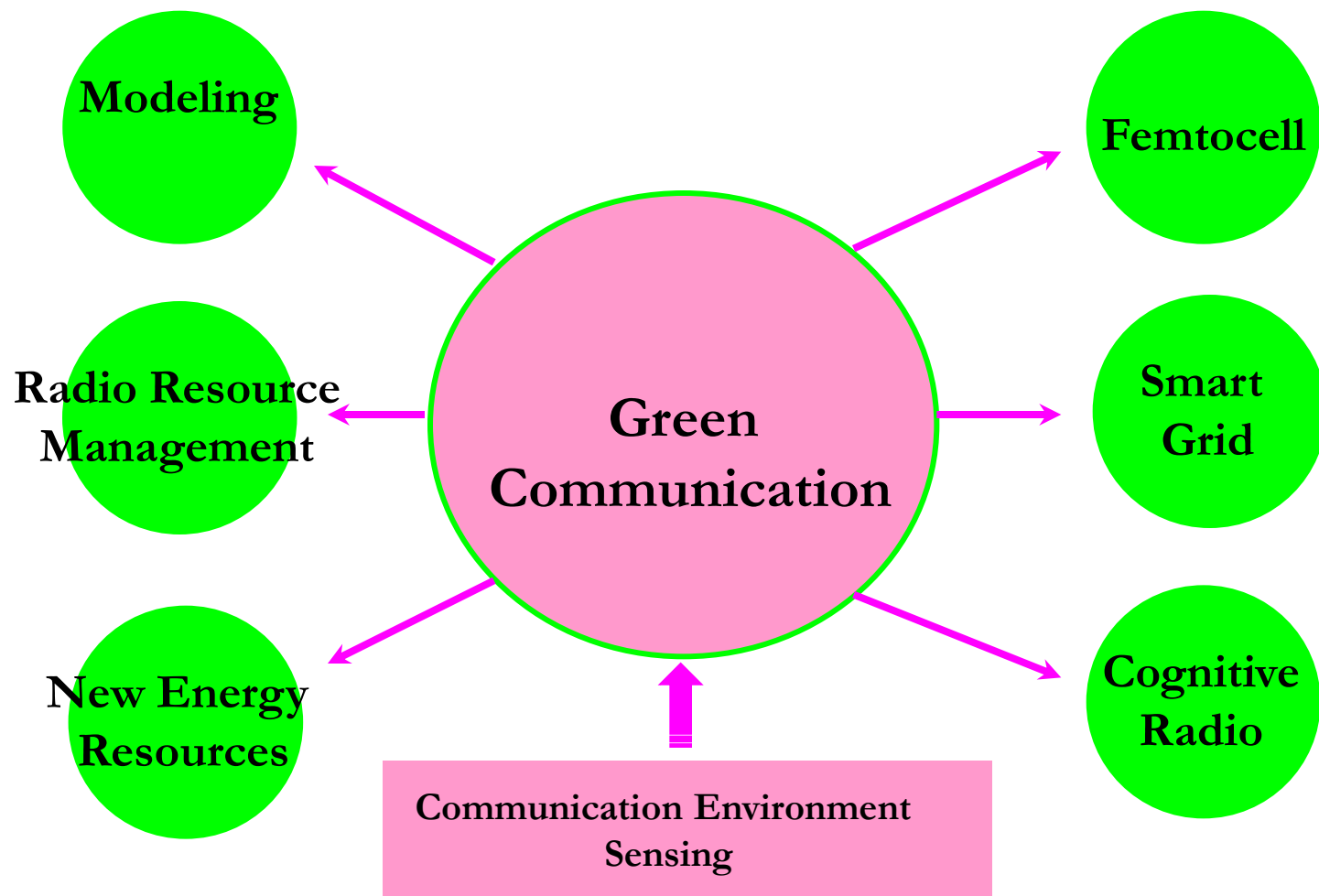❑ **Open problems and key technologies**

- ✓ Modeling and analysis of spectrum-energy relationship
- ✓ Sensing the communication environment
- ✓ Network convergence, radio optimization, cross-layer design

Green Communication by Environment Sensing

Modeling

Femtocell

Radio Resource Management

Green Communication

Smart Grid

New Energy Resources

Cognitive Radio

Communication Environment Sensing

New decade of CLD

❑ **Separate-layer design**

   ✓   Uniform standard for easy interconnection

   ✓   Layers optimized separately, local optimum

❑ **Cross-layer design（CLD）**

   ✓   Layers optimized jointly, global optimum

   ✓   **First decade of CLD has passed (2000-2010)**

First decade of CLD

❑ **Overview**

   ✓ Non-systematic (optimize how many layers, two or more? Optimization based or heuristic method? Bottom-up or Top down? …)

   ✓ Far away from a mature methodology of CLD
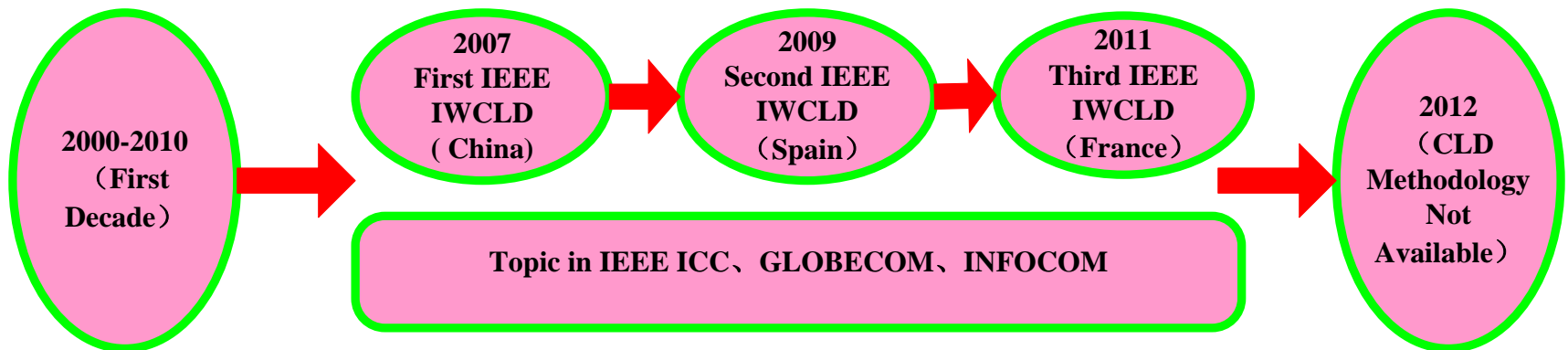
Envisioning the Second Decade

2010-2020
（Second
Decade）

What should we do?
How to do?

2020: Mature
Methodology
of CLD

CLD Methodology for Network Optimization
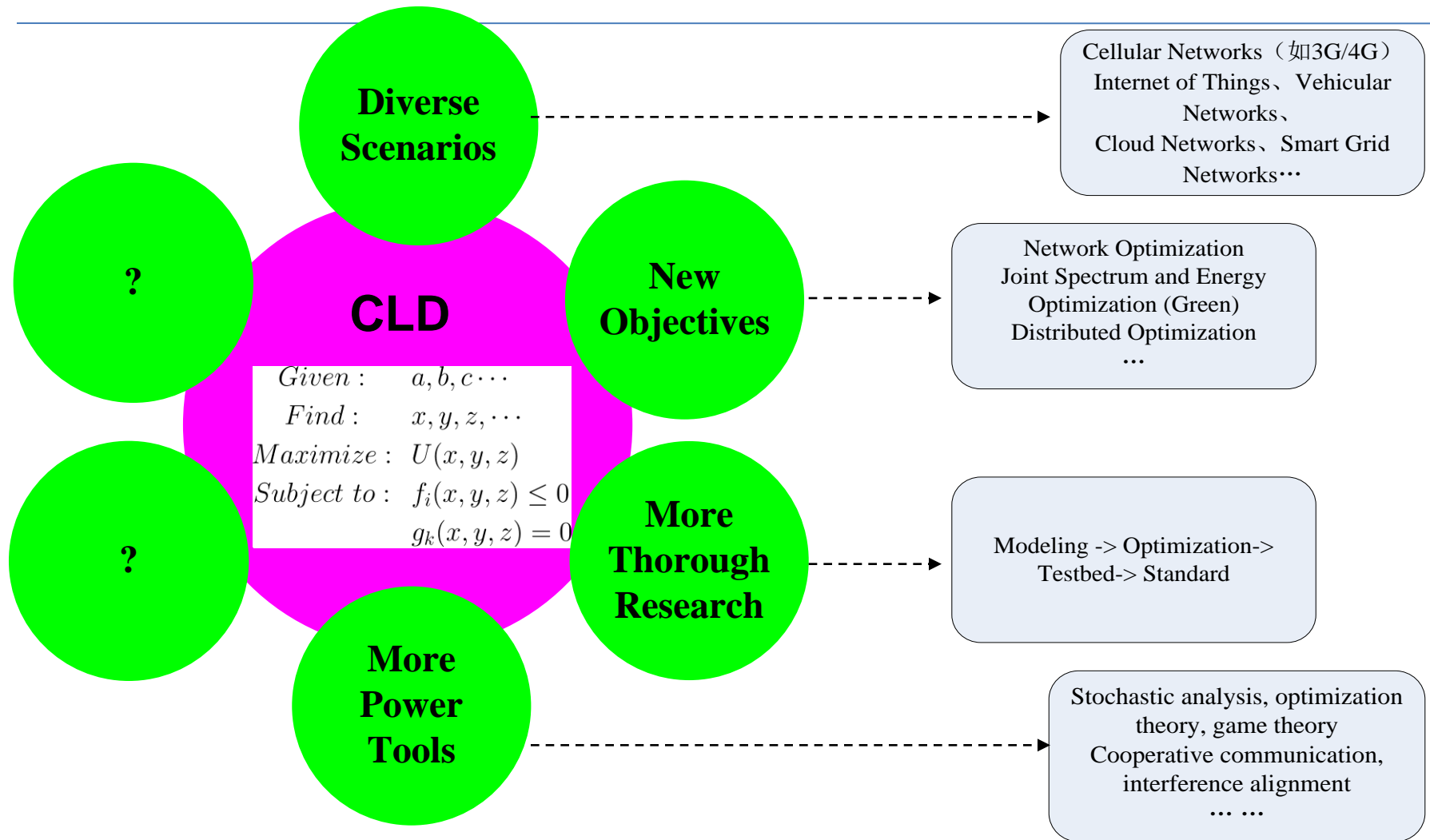
Diverse Scenarios ---→ Cellular Networks（如3G/4G）Internet of Things、Vehicular Networks、Cloud Networks、Smart Grid Networks···

?

CLD

$$Given: \quad a, b, c \cdots$$
$$Find: \quad x, y, z, \cdots$$
$$Maximize: \quad U(x, y, z)$$
$$Subject\ to: \quad f_i(x, y, z) \leq 0$$
$$g_k(x, y, z) = 0$$

?

New Objectives ---→ Network Optimization Joint Spectrum and Energy Optimization (Green) Distributed Optimization ···

More Thorough Research ---→ Modeling -> Optimization-> Testbed-> Standard

More Power Tools ---→ Stochastic analysis, optimization theory, game theory Cooperative communication, interference alignment ... ...

Rethink of Interference Management

- ❑ **Conventional**
  - ✓ User-centric interference processing
  - ✓ Suppression, avoidance

- ❑ **Road ahead : Interference management**
  - ✓ Network-centric interference management
  - ✓ Address inference statistically (random channel coding) → Exact interference control (IA needs full and exact channel state information)
  - ✓ Exploit degree of freedom (DoF) through user cooperation

- ❑ **Open problems and key technologies**
  - ✓ How to approach network capacity through interference management
  - ✓ How to exploit DoF through Interference management (e.g., IA)

Interference Management

- MSE, zero-forcing

- Using orthogonal channels (FDMA, TDMA, etc.)

- Regard interference as noise

Cancel

Avoid

Neglect

Interference Management

IA

- IA, joint multiuser precoding

Network Capacity

Emerging Applications

❑ **New Areas**

    ✓ Transportation → Intelligent Transportation System (ITS) , Vehicular Networks, Communication on Express Train

    ✓ National Grid → Smart Grid, Green Communication

    ✓ Public Health → Remote healthcare network, body-area sensor network (BASN)

    ✓ Social Security → Internet of Things

❑ **Open problems and key technologies**

    ✓ Data collection, fusion and mining

    ✓ Cloud computing

    ✓ Scheduling

Summary

❑ **Future Wireless Communication**

 ✓ Link-centric   →   Network-centric

 ✓ User-based   →   System-based

 ✓ Separate-layer   →   Cross-layer

 ✓ Communication   →   Diverse applications

❑ **What to do?**

 ✓ Cross discipline

 ✓ Cross layer

Thanks for your attention !