Communications Technologies for 2020 and Beyond: An Energy-Efficient Perspective with Application to Automation

by

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Outline

- A Bit of History
- Desirable Attributes of a 5G Wireless Systems
- Energy Saving in Base Stations
- 5G Research Topics at UBC
- Internet Of Everything and Automation
- Conclusions

Fundamental Premise of this Presentation

- There is no point in having information unless you can communicate it.

- IoE allows objects to be sensed and controlled remotely.

- Wireless Networks for industrial automation enhance the ability to gather time critical information, digest it, and react.

- Projections are for 50 Billion objects by 2020.

Fessenden sent a radio message one kilometre in 1900. Corbis-Magma

Canadian inventor scored a radio first

Reginald Fessenden proved that he was right and the world was wrong

Reginald Aubrey Fessenden, who died 68 years ago this week, spoke the first words ever heard on the radio. He was a classical scholar who also patented 500 inventions. He was 6-foot-2 with a ginger Viking beard and he occasionally wore a flowing black cape.

tried to broadcast voice. On Dec. 23, 1900, he sent a message one kilometre: "One, two, three, four. Is it snowing where you are, Mr. Thiessen? If it is, telegraph back and let me know." The response came almost at once.

Reginald Aubrey Fessenden

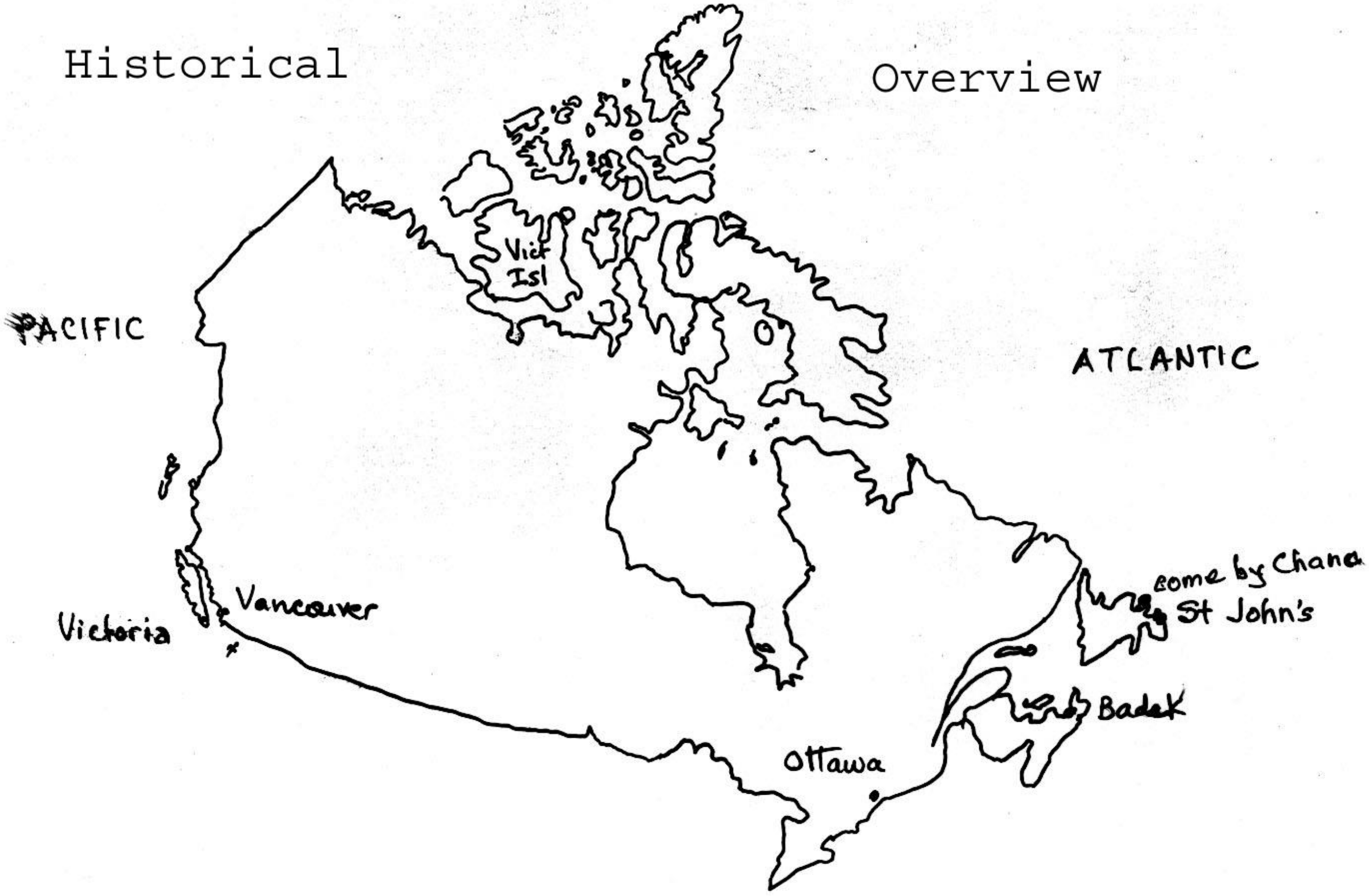
(1866 – 1932)

- **23 December 1900**

  " Hello! Test 1, 2, 3, 4. Is it snowing where you are,

  Mr. Thiessen? "

Historical Overview



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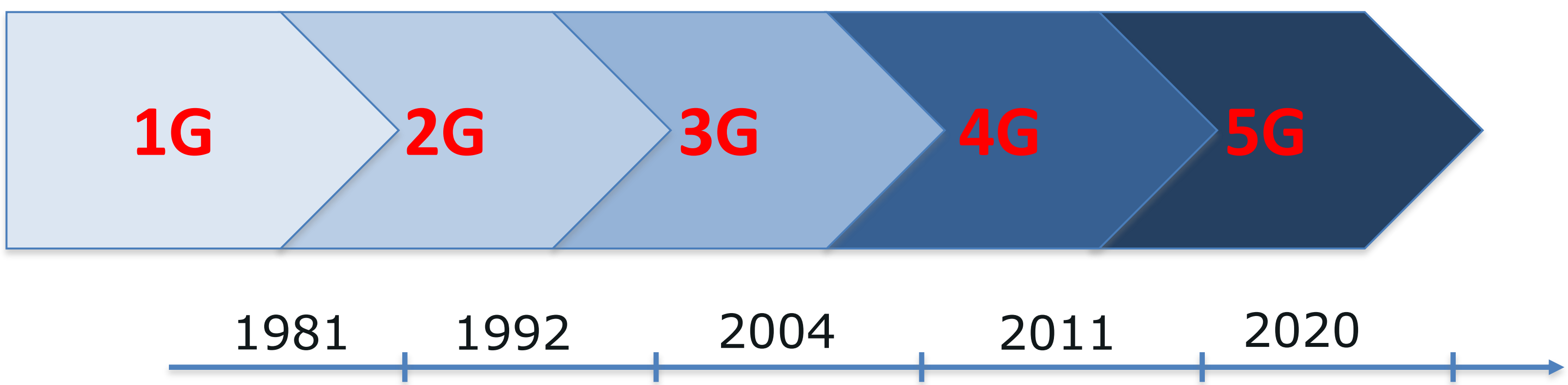
The 5G Paradigm Shifts

- Development of 3G and 4G was motivated by the booming demand of higher data rates.
- 5G is developed to serve new traffic types as M2M, smart grids, smart homes, and e-health.
- There is still a strong demand for higher capacity networks.
- 5G networks must be energy-efficient and sustainable.
- 5G must offer a new paradigm shift from LTE-Advanced.

The 5G Timeline

- First release of LTE-Advanced was in March 2011.

- Standard bodies and industry aim to release the 5G standard between 2017-2019.



Desirable Attributes of 5G

- **Data rate:** 1 to 10 Gb/s
- **Capacity:** 10,000 times more traffic, 10-100 times more devices
- **Latency:** less than 1 ms
- **Coverage:** data rates of more than 1 Gb/s anywhere, anytime with high reliability
- **Longer battery life:** e.g. one decade battery life for sensors

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Growth in Cellular Data Traffic

- Tremendous growth in cellular data traffic
  - Portable smart devices: iPhone, iPad, Android, Kindle, etc.
  - Success of social networking: Facebook, LinkedIn, Twitter, WhatsApp, and Viber
- Legions of connected devices and high traffic volume.
- High data rate and low latency requirements.
- Disparate user requirements and characteristics.

Cellular Energy Consumption

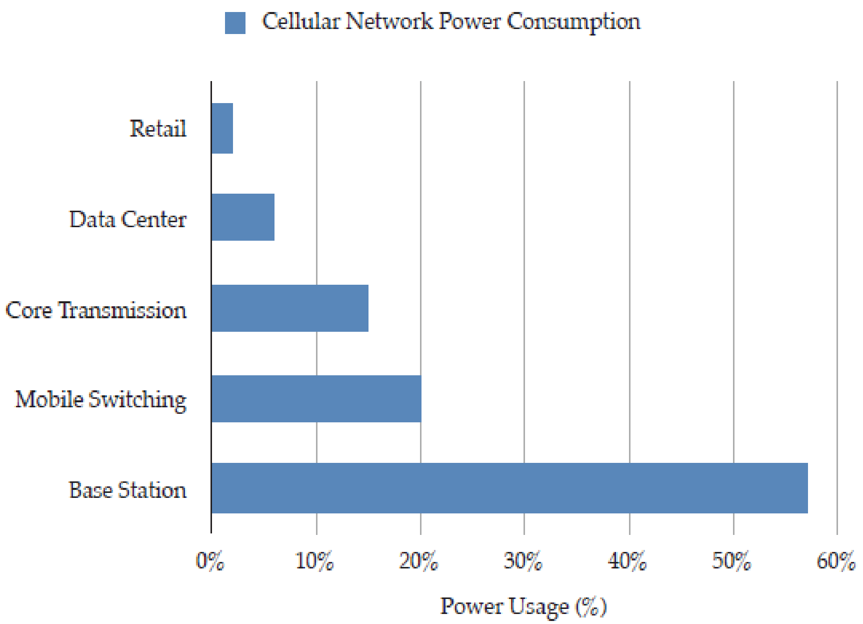
- Information and Communication Technology (ICT) represents around 2% of total carbon emissions.
    - Mobile networks 0.2%;
    - Fixed networks 0.4%;
    - The remaining 1.4% being IT.

- Huge growth in the number of off-grid, generator-powered BSs
    - Grown from **290,000** to **640,000** in **last five years**
    - Consume **$14.6 billion** worth of diesel per year

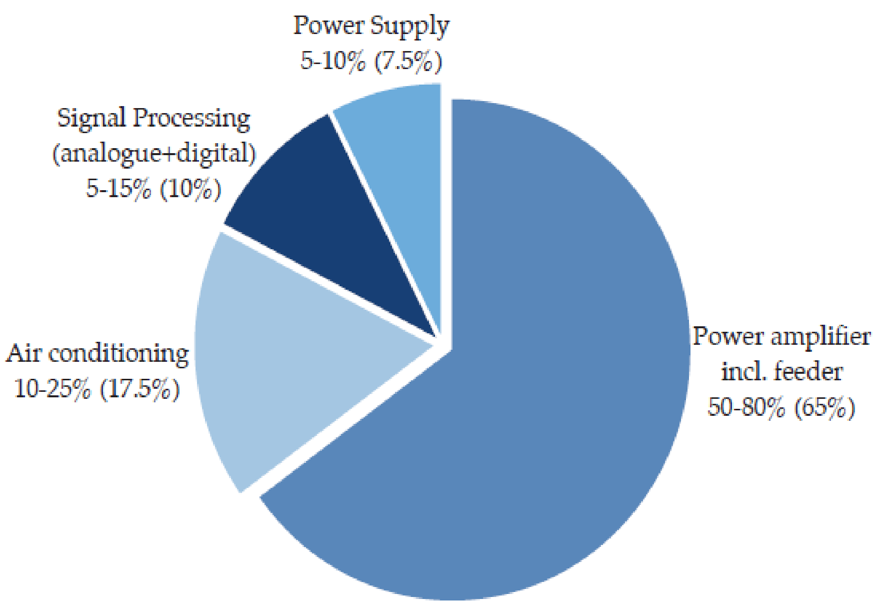
- Significant operational expenditures (OPEX) due to mobile network energy consumption: **100 Tera Watt-Hour per year**

- Energy efficiency is not addressed swiftly in future wireless networks, the environmental and financial impact could be high.

Cellular Energy Consumption



Power consumption of a typical wireless cellular network.



Power consumption distribution in radio base stations.

Energy Saving in BS:
Power Amplifier

- Three essential parts of a BS: **radio**, **baseband** and **feeder**.

- Radio consumes more than 80% of a BSs energy requirements, out of which, power amplifier (PA) consumes almost 50%.

- Modern BSs are inefficient because of their need for amplifier linearity and high peak-to-average power ratio (PAPR).

- To obtain high linearity, PAs have to operate well below saturation, resulting in poor power efficiency.

- PAs based on digital pre-distorted Doherty-architectures, GaN (Aluminum Gallium nitride) and switch-mode are more promising.

Energy Saving in BS:
Power Saving Protocols

- In current cellular network architectures, BS and mobile terminal continuously transmit pilot signals.

- An intuitive way to save power is to switch off the transceivers whenever there is no need to transmit or receive.

- LTE introduces power saving protocols for mobile handsets:
  - Discontinuous Reception (DRX) mode.
  - Discontinuous Transmission (DTX) mode.

- Cellular traffic varies spatially and temporally per hour.
  - BSs operate inefficiently under low load conditions especially during the nighttime.

- Power saving protocols for BSs need to be developed in future.

有朋自远方来，不亦乐乎？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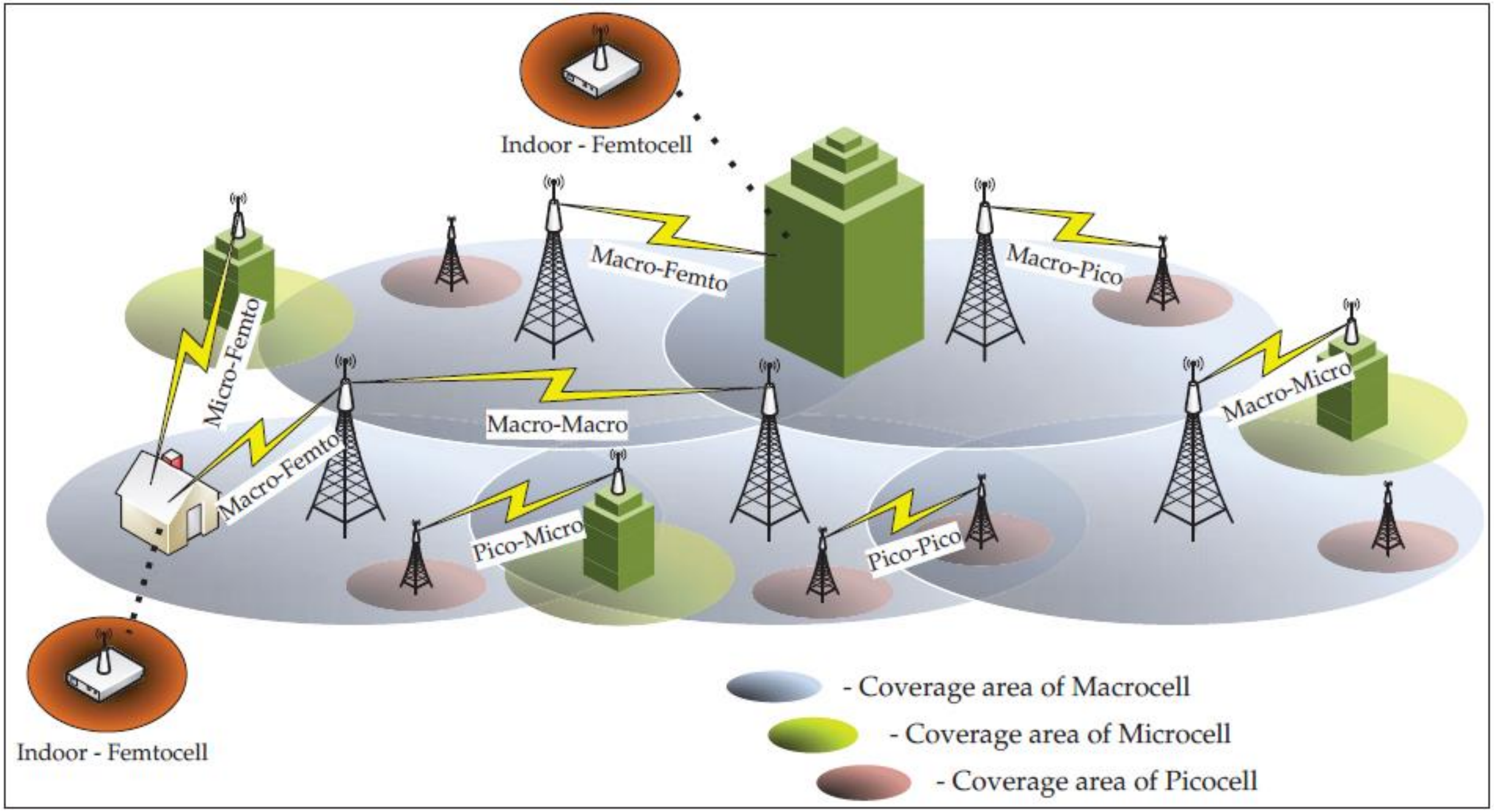
5G Research Topics at UBC:
Energy Efficiency in Heterogeneous Networks

A typical heterogeneous network



Macrocell~1-30km, Microcell~200-2000m, Pico-cell~4-200m, Femtocell~order 10m

5G Research Topics at UBC:
Energy Efficiency in Heterogeneous Networks

Energy efficiency maximization in cognitive downlink two-tier networks:

- Spectrum sharing between macro-cell and small cells
- Each small-cell maximizes its energy efficiency
- Solution: Parametric convex optimization framework

R. Ramamonjison, V. K. Bhargava, “Energy efficiency maximization framework in cognitive two-tier networks," *IEEE Transactions on Wireless Communications.*, vol. 14, no. 3, pp. 1468-1479, 2015.

5G Research Topics at UBC:
Energy Efficiency in Heterogeneous Networks

- Energy efficient resource allocation with hybrid power sources:
  - Here, small cells have access to both conventional power grid and renewable energy-harvesting source.
  - Online stochastic optimization is used to improve energy usage decisions.
- Challenges for practical implementations:
  - Distributed coordination
  - Signaling overhead between cells

Joint Cell Association & Resource Allocation

- Cell association and radio access technology (RAT) selection in 5G multi-tier HetNets – critical for Base Station densification.
  - Interference management (IM)
  - Throughput maximization
  - Energy efficiency and QoS considerations

- Cell association approaches for load balancing and IM
  - Cell range expansion (CRE) of small cells and almost blank sub-frames (ABS) configuration of macro-cells
  - RAT selection in a multi-RAT architecture
  - Relaxed optimization and decomposition
  - Stochastic geometry

Joint Cell Association & Resource Allocation

- QoS-driven cell association
  Joint consideration of resource and QoS constraints
  - Downlink rate maximization
  - Downlink outage minimization
  - Energy efficiency maximization

- Joint downlink and uplink aware cell association
  - Weighted sum utility of downlink and uplink
  - Separate QoS considerations for downlink and uplink
  - A two-phase distributed solution by relaxed optimization and dual decomposition

• Boostanimehr, H.; Bhargava, V.K., "Joint Downlink and Uplink Aware Cell Association in HetNets with QoS Provisioning," Wireless Communications, IEEE Transactions on, June 2015

• Boostanimehr, H.; Bhargava, V.K., "Unified and Distributed QoS-Driven Cell Association Algorithms in Heterogeneous Networks," Wireless Communications, IEEE Transactions on , vol.14, no.3, pp.1650,1662, March 2015

Joint Cell Association & Resource Allocation

- Small cell solutions with wireless backhaul have not as yet been adequately considered

- Joint cell association and small cell wireless backhaul bandwidth allocation in HetNets
  - Massive MIMO at macro base stations:
    Eliminating inter-tier interference
  - In-band wireless backhaul for small cells:
    Low in cost, high in spectral efficiency
  - Wireless backhaul bandwidth allocation strategies:
    Unified v.s. per-small-cell allocation
  - IM scheme for per-small-cell bandwidth allocation:
    Reverse TDD and soft frequency reuse (SFR)

• N. Wang, E. Hossain, and V. K. Bhargava, "Joint downlink cell association and wireless backhaul resource allocation for large-scale MIMO two-tier HetNets," under 2^{nd} round of review, IEEE Transactions on Wireless Communications.

Device-to-Device Communication

- In conventional cellular system, devices can only communicate through base station.

- In 5G the devices are allowed to play a more active role: Network controlled device-to-device (D2D) communication.

- In D2D communication neighboring devices can communicate with each other directly over licensed bands.

- Although D2D users communicate directly, they remain controlled under the base station.

- D2D can enhance the performance of the system by reusing the radio resources.

- D2D is a key feature for 5G.

Device-to-Device Communication

- D2D advantages:
  - Reducing latency
  - Reducing power consumption
  - Increasing peak data rate
- D2D challenges:
  - Designing D2D communication protocol
  - Interference management
  - Privacy and security

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Internet Of Everything (IoE)

- Fabric of a truly connected world.
- Depend on four key dimensions
  1. People: mobile and wearable technologies
  2. Processes: from sensors to decision-makers
  3. Data: human-generated and machine-logged
  4. Things: from cars to home appliances to security cameras.
- Each dimension brings great opportunities and challenges.

Some Usage Scenarios for IoE

1. **Ubiquitous health monitoring:**
   - Monitor vital signs, sleep patterns and physical activities
   - Request help in case of emergencies

2. **Real-time infrastructure management**
   - Monitor road and bridge conditions to prevent accidents
   - Sustainable provision and usage of water and electricity by connecting utilities, distributions and users.

3. **Smart building automation**
   - Lighting, heating, appliances, security devices and entertainment systems
   - Improve convenience, comfort and security.

Wireless Communications and Automation

- Automated mining.
- Automated video surveillance.
- Automated highway system.
- Automated waste management
- Industrial automation.

Challenges of IoE

1.Policy issues:

- Monitor vital signs, sleep patterns and physical activities
- Behavioral and economic impact to Society

2.Technical challenges:

- Data deluge: need vastly more efficient storage and quicker access to relevant data
- Need for superior communication systems:
  - Greater network capacity to connect almost “everything.”
  - More predicable quality of service to support diverse applications.

Wireless systems for IoE

- IoE depends on multiple technologies.
- Wireless technology is key for connectivity.
- Some important wireless systems for IoE:
  - Millimeter-wave small-cell networks
  - Energy-efficient body area network systems
  - Underground and underwater relay systems
  - Inter-vehicular wireless systems

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Conclusions

- Exponential growth of mobile data traffic and new service types spurred the demand for 5G: Higher data rate and throughput, lower latency, better coverage, improved spectral and energy efficiency.

- BSs account for a major portion of energy consumption in a cellular network and new hardware and system level features are required to improve efficiency.

- Efficient energy-saving BS technologies were discussed.

- Broader perspectives and other paradigm-shifting technologies for 5G such as: energy efficiency in HetNets, joint cell association and resource allocation in HetNets and network controlled D2D communication, were outlined.

- Applications to IoE and Automation were presented.

绝　句

杜 甫

两个黄鹂鸣翠柳，

一行白鹭上青天。

窗含西岭千秋雪，

门泊东吴万里船。

Energy Harvesting Wireless Networks: Architectures, Protocols, and Applications

by

Dusit Niyato, Ekram Hossain, Dong In Kim, Vijay Bhargava and Lot Shafai

Monograph proposal under consideration by Cambridge University Press