Cooperative Wireless Networks for Better Green Services

Yang Yang

Shanghai Research Center for Wireless Communications
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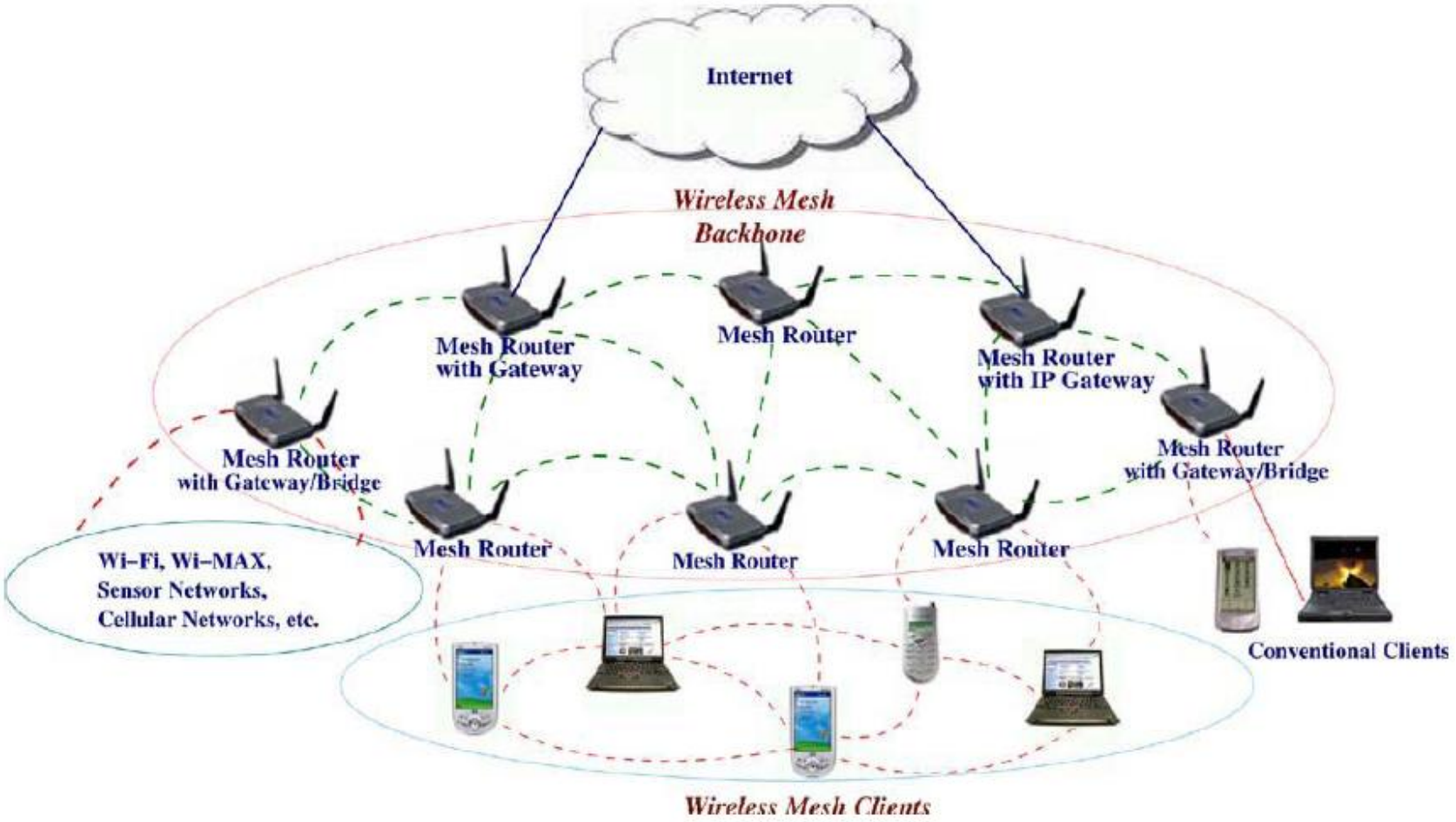
Outline

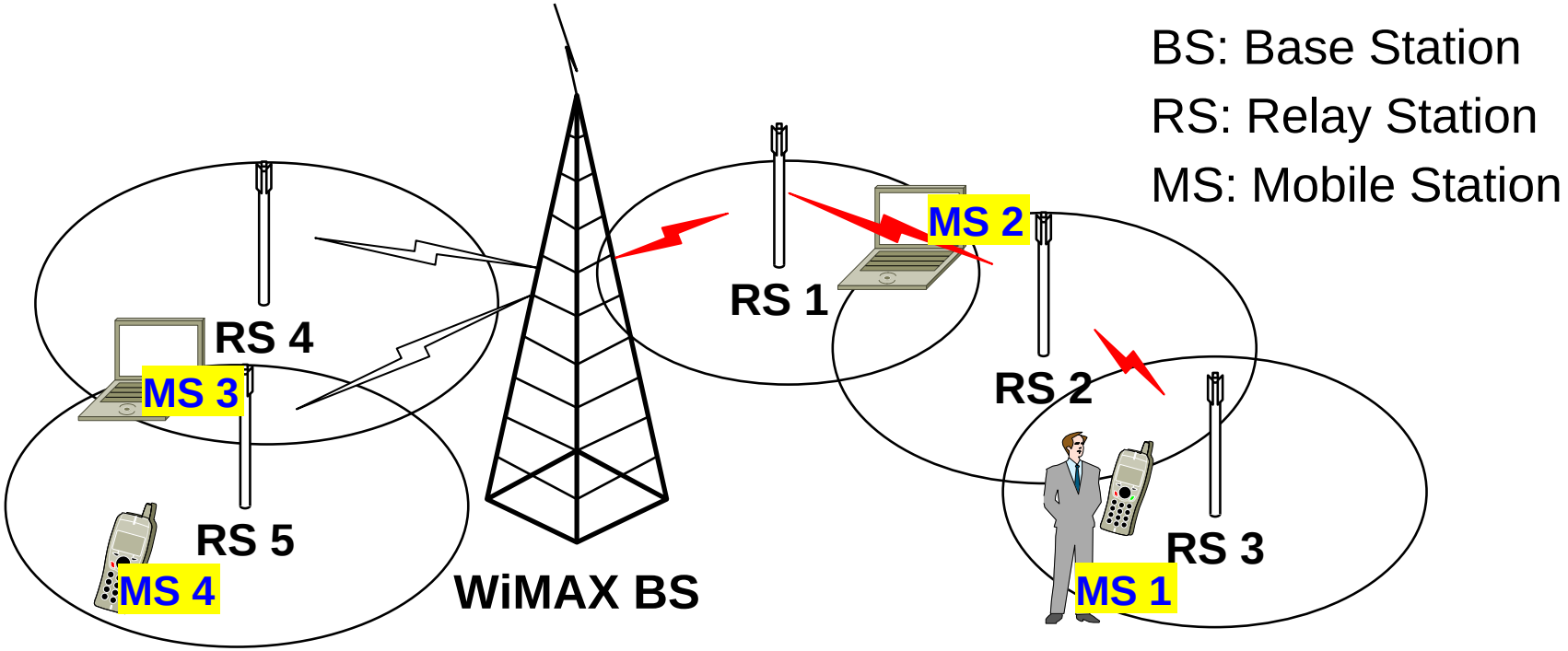
- Cooperation in multi-hop wireless networks
  - Problem definition
  - Multi-hop delay analysis
  - Results and discussions
- Cooperation across multiple wireless networks
  - Problem definition
  - Energy efficient communications
  - Results and discussions
- Conclusions

Wireless Mesh Networks



Wireless Relay Networks

- Relay has been adopted by IEEE 802.11s (WLAN), 802.16j (WiMAX) and LTE-Advanced (4G) standards



Wireless Multi-hop Networks

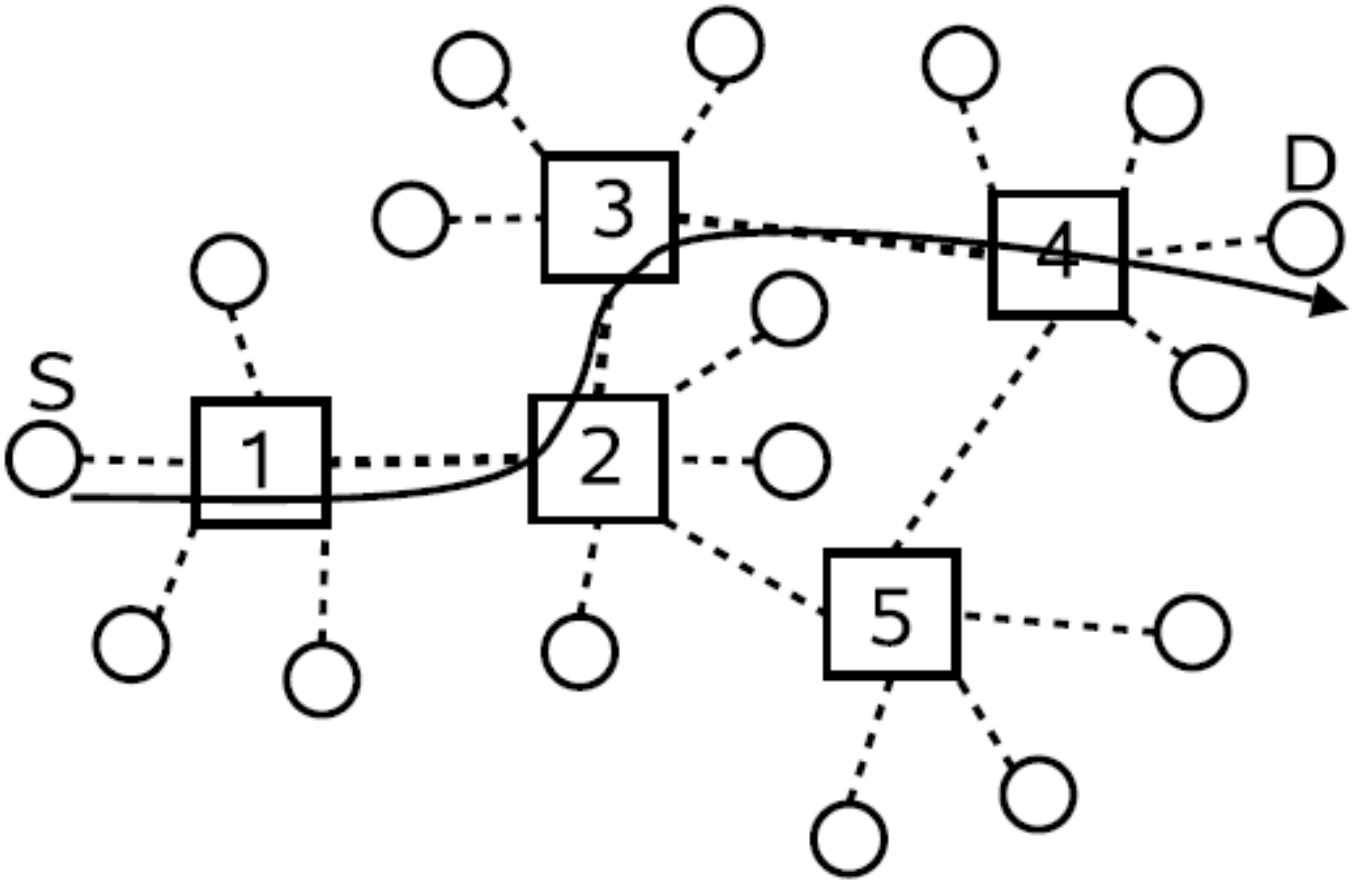
- Advantages
  - Capacity and coverage enhancements
  - Multi-hop and multi-path communications
  - Flexible network architecture
  - Easy deployment and self-configuration
  - Low installation and maintenance costs
  - Multiple radios and access methods
  - Efficient frequency reuse
  - …

Problem Definition

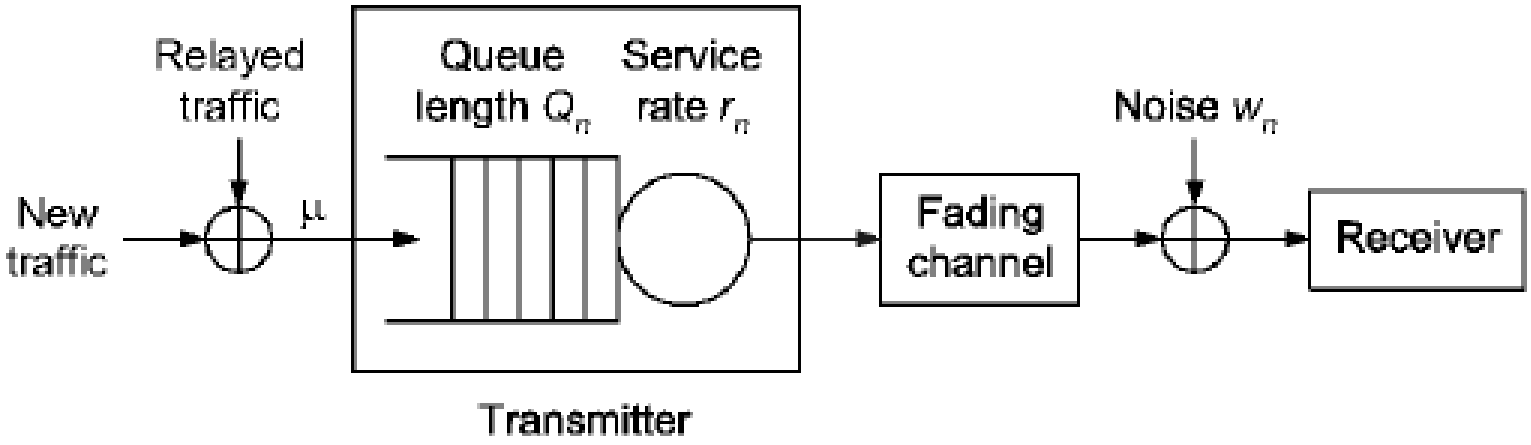
- How to analyse, predict and guarantee multi-hop delay performance?
  - **Physical layer:** dynamic radio channel conditions
  - **MAC/data link layer:** queueing and scheduling
  - **Network layer:** routing
  - **Application layer:** traffic load and characteristics

This is the BIG challenge for delay-sensitive applications, such as video streaming and interactive gaming.

System Model-1



System Model-2



- Multi-hop communication path
- Independent fading channel
- Additive white Gaussian noise
- Independent new traffic and correlated relay traffic
- A fluid traffic model with infinitesimal packet size
- A single queue with first-come first-served policy

Multi-hop Delay Analysis-1

- For an *h*-hop communication path, let *Di* be the steady-state delay at the *i*-th hop.
- Delay performance of a single-hop wireless link
  - Delay bound violation probability (DBVP) and cumulative distribution function (CDF)

$$Prob\{D_1 > D_{max}\} \approx \gamma\, e^{-\theta\, D_{max}}$$

$$\begin{aligned} F_{D_1}(x) &= Prob\{D_1 \le x\} \\ &= 1 - \gamma e^{-\theta\, x}, \qquad x \ge 0 \end{aligned}$$

  - Probability density function (PDF)

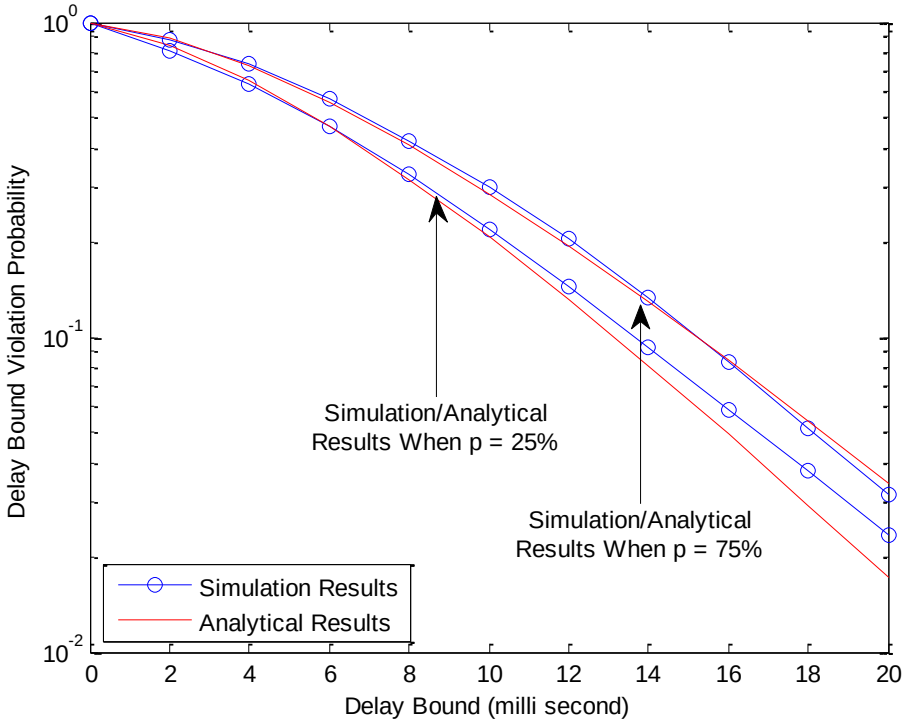
$$\begin{aligned} f_{D_1}(x) &= \frac{d}{dx} F_{D_1}(x) \\ &= \gamma\theta\, e^{-\theta\, x} + (1-\gamma)\delta(x) \end{aligned}$$

Multi-hop Delay Analysis-2

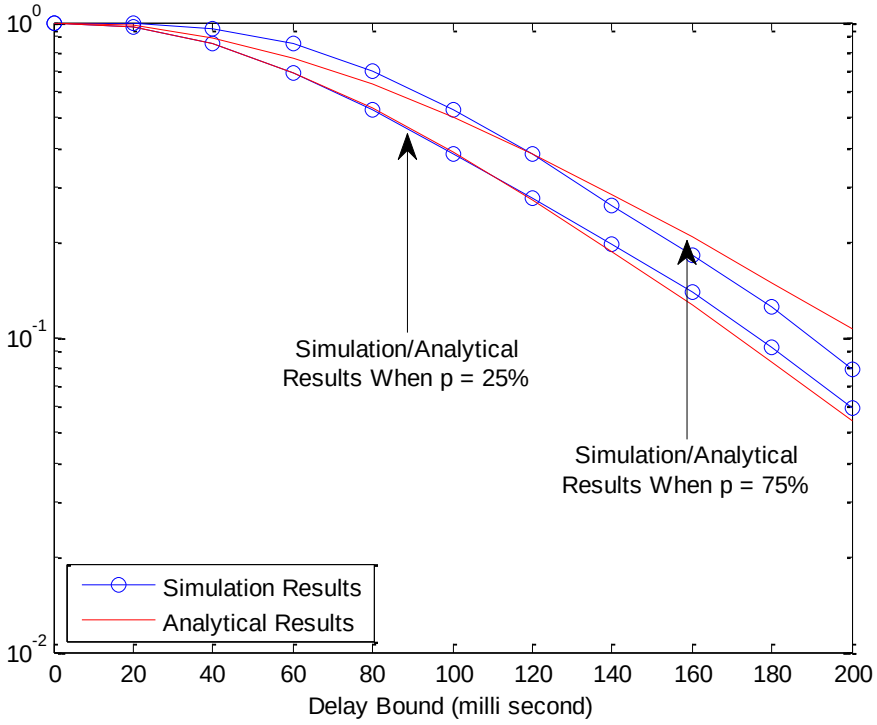
- Delay performance of a multi-hop wireless link
  - Cross-traffic and traffic correlation index ***p***
  - Traffic load is uniformly distributed
  - After ***h*** hops, only a p^h portion of the total traffic from the source arrives at the intended destination

$$\Pr\left(\sum_{i=1}^{h} D_i > x\right) = \sum_{i=1}^{h}\left(\prod_{j=1, i\neq j}^{h}\left(1+\frac{\gamma_j \cdot \theta_i}{\theta_j - \theta_i}\right)\right)\cdot \gamma_i \cdot \exp(-\theta_i \cdot x)$$

Delay Bound Violation Probability (3 hops)



μ=75kbps

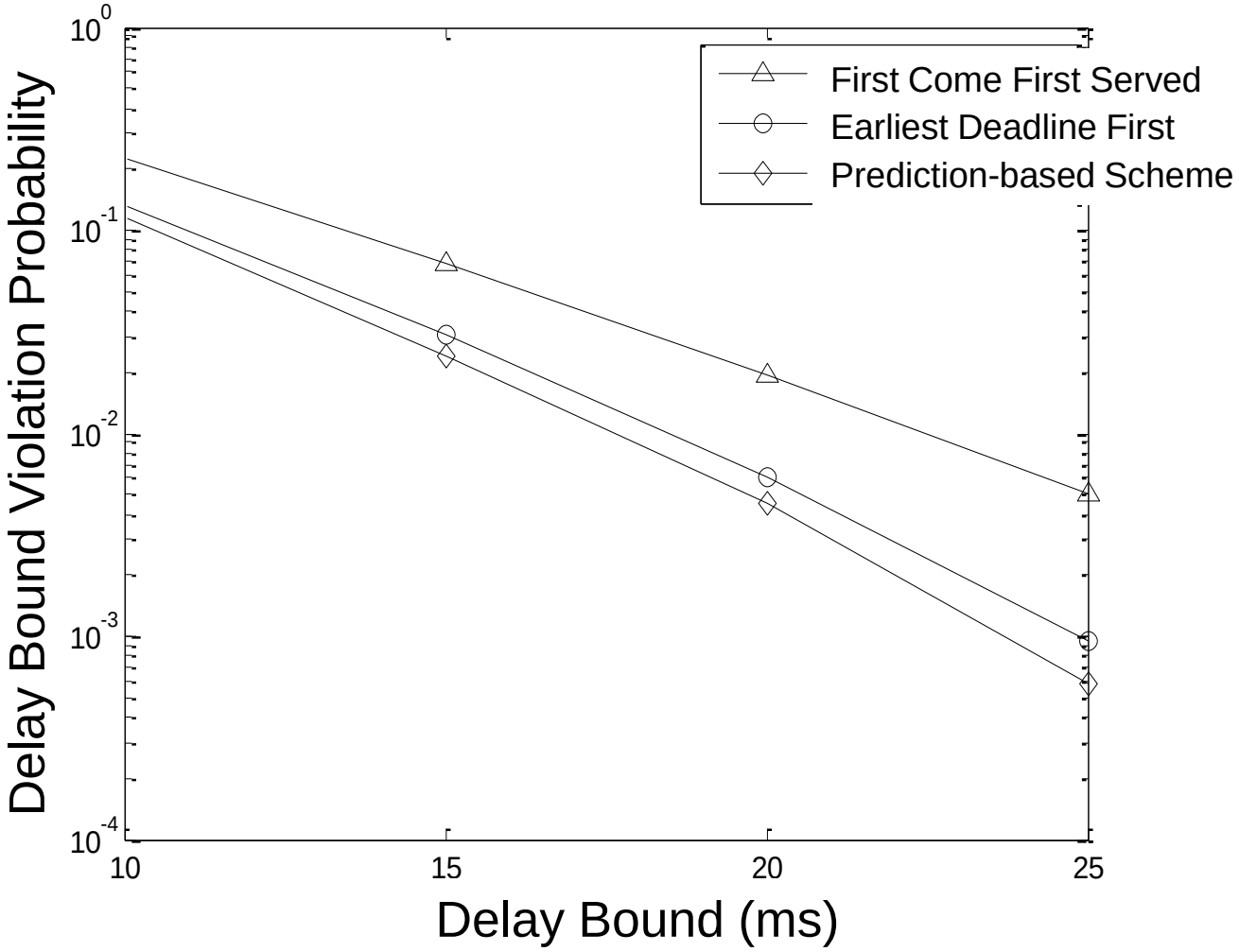


μ=85kbps

Average Delay and Delay Jitter Performance

	Average Delay	Delay Jitter
Traffic load & Correlation	**μ= 75kbps and p = 0.25**	
Sim/Ana Results (ms)	6.6 / 6.7	5.3 / 4.8
Traffic load & Correlation	**μ= 75kbps and p = 0.75**	
Sim/Ana Results (ms)	7.9 / 7.9	5.4 / 5.5
Traffic load & Correlation	**μ= 85kbps and p = 0.25**	
Sim/Ana Results (ms)	95.3 / 95.1	55.2 / 56.9
Traffic load & Correlation	**μ= 85kbps and p = 0.75**	
Sim/Ana Results (ms)	113.1 / 112.9	53.8 / 65.4

Prediction-based Packet Scheduling Algorithm
fm=30 Hz, μ=75kbps, Rayleigh fading channel



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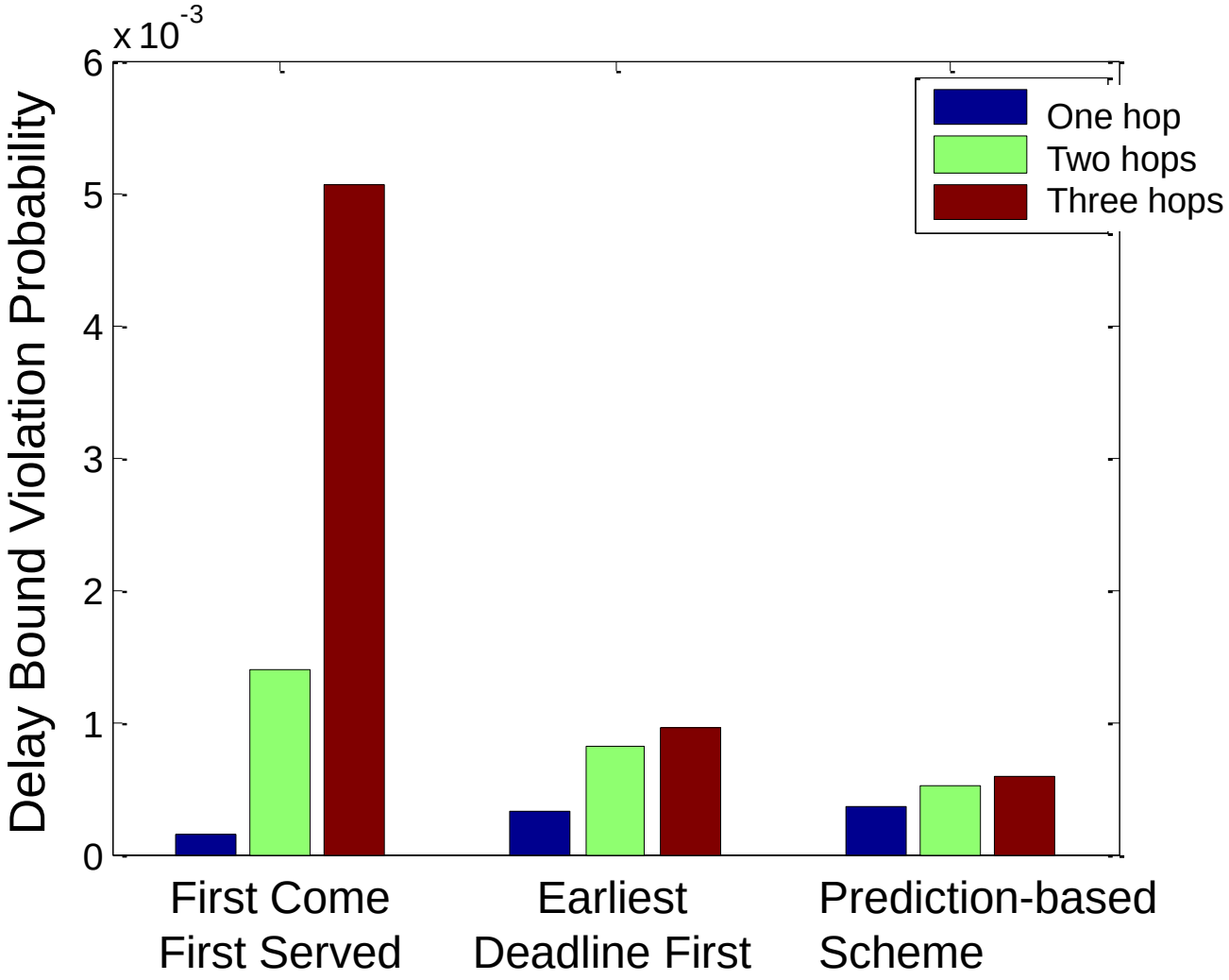
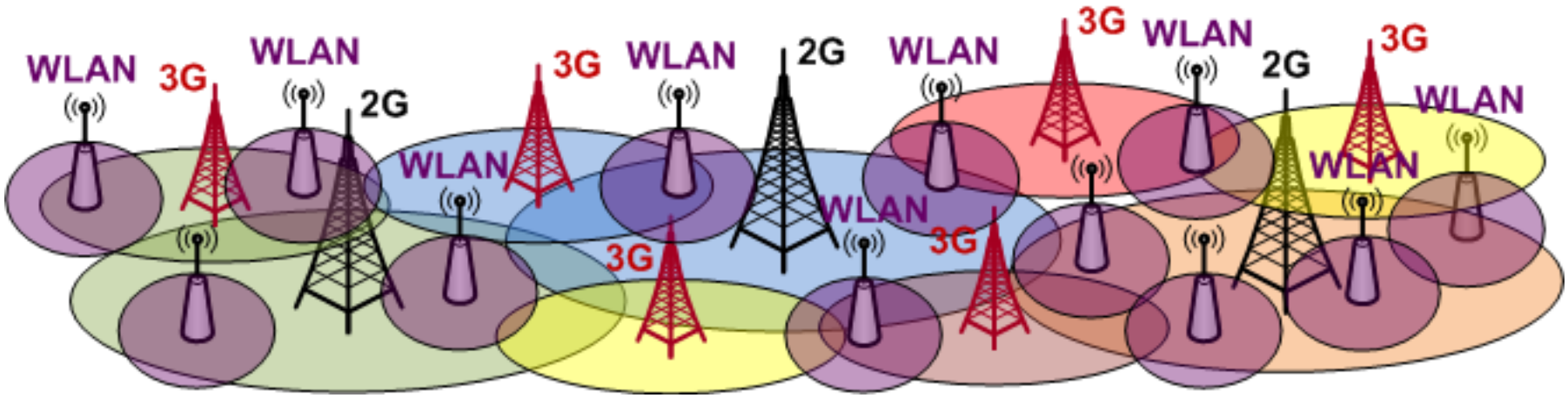


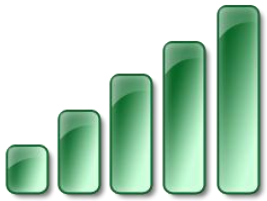
Heterogeneous Wireless Networks

- Significant contributions to social progress and economic growth
- Overlapped network and service coverage
- Strong competition and waste of resources
- More electromagnetic interference (EMI) and radiation pollution



Problem Definition

- We all want strong signals … anywhere and anytime … so are the operators
- But,
  - **Is this necessary?**
  - **Is this efficient?**
  - **Is this healthy?**
  - **Is this sustainable?**



Facts & Figures – Energy Consumption and Greenhouse Gas (GHG) Emission

- ICT is the 5th largest industry in energy consumption (2%-4%, comparable to aviation industry), and growing fast
- In 2009, the total electricity consumption of three mobile operators in China is about 29B KW·H, equivalent to 11.5M tons CO_2 emission.

Sources: IEA, GESI, Climate Change Group, MIIT

Facts & Figures – Electromagnetic Interference and Radiation Pollution

- By the end of 2010, there are more than 1.5M mobile base stations and 850M mobile users in China
  - 2G: 969K, 3G: 528K, WLAN: 260K, growing fast
- It is becoming harder and harder to keep the EMI and radiation pollution levels less than the national standard, i.e. 40μW/cm^2.

Sources: China Mobile, China Telecom and China Unicom

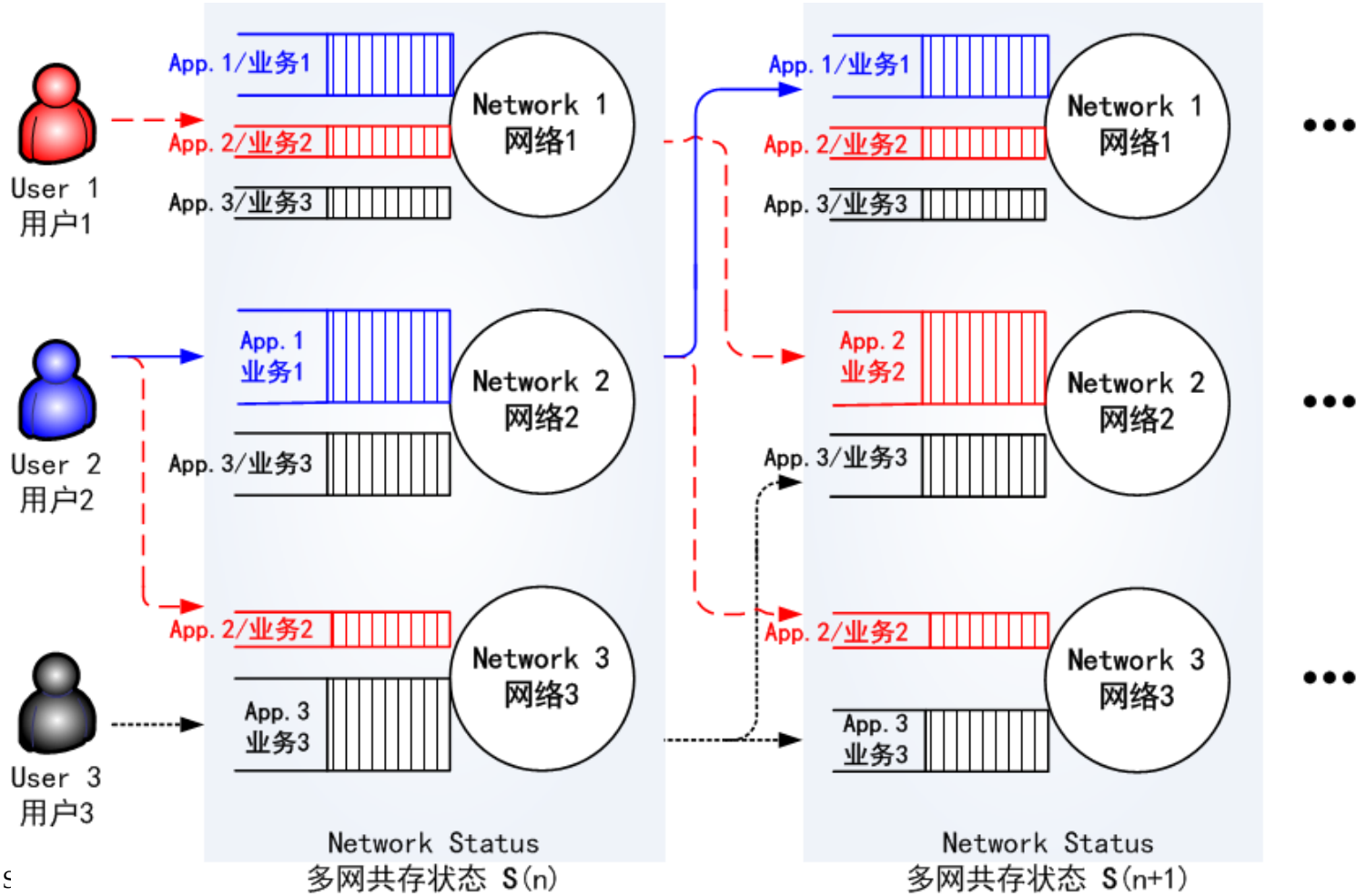
Cooperative Wireless Networks

Cross-network cooperation to match user requirements and traffic distributions.

- Enable cross-network resource sharing, load balancing, and interference avoidance
- Reduce energy consumption and GHG emission
- Reduce EMI and radiation pollution
- Improve cross-network services and applications
- Support sustainable business/economic growth

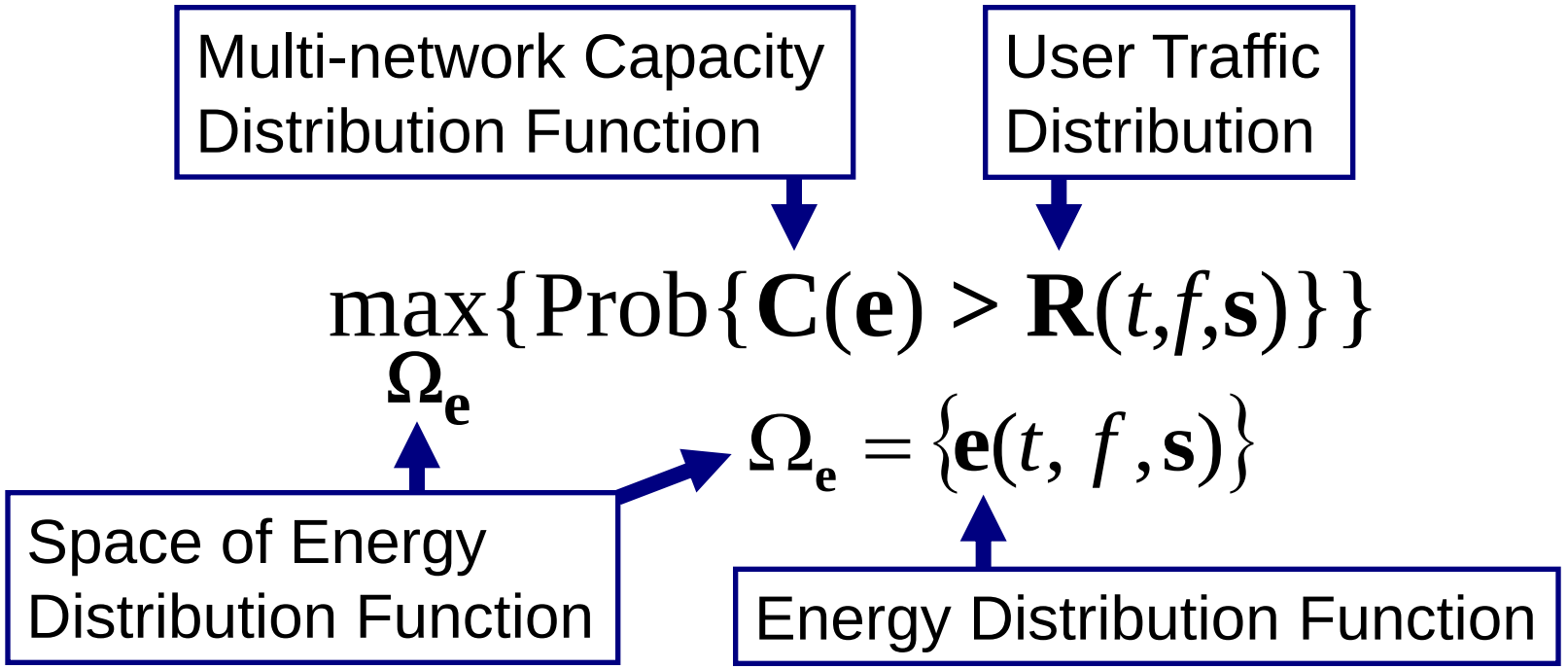
Research Challenges-1

- Dynamics user requirements and traffic distributions



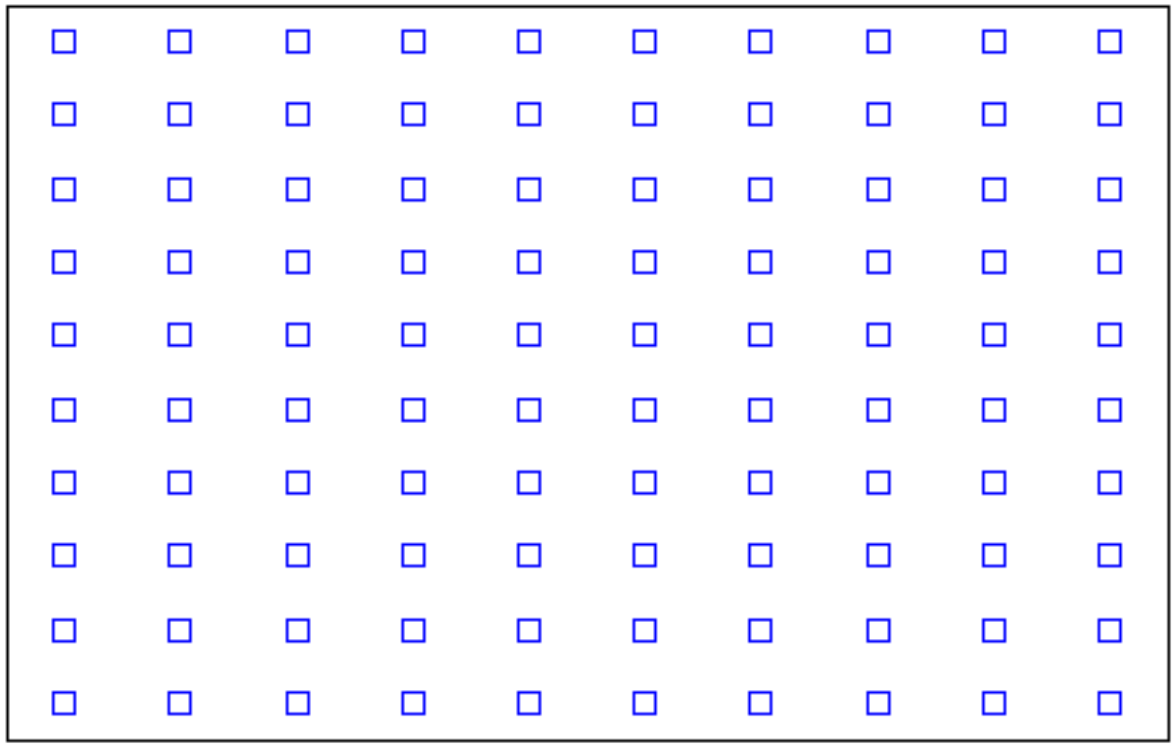
Research Challenges-2

- To track and match the statistics of periodic and bursty user requirements and traffic distributions



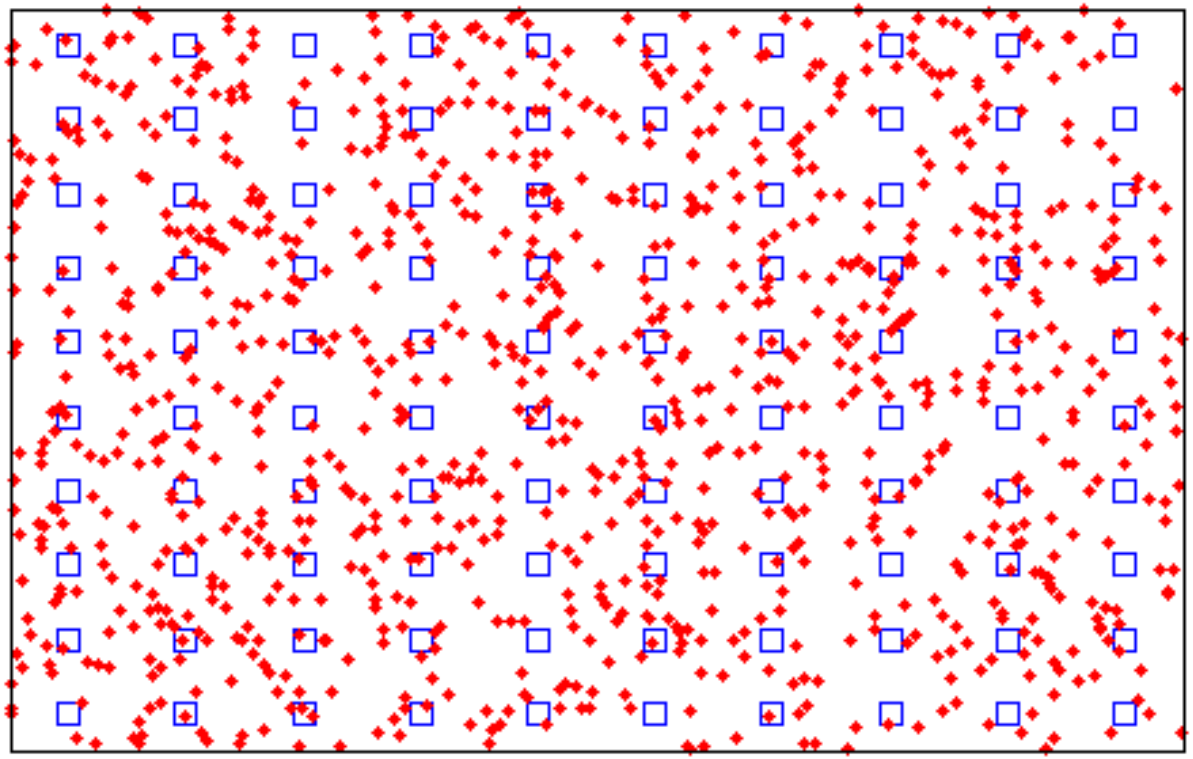
Simulation Results-1

- Distribution of 100 base stations



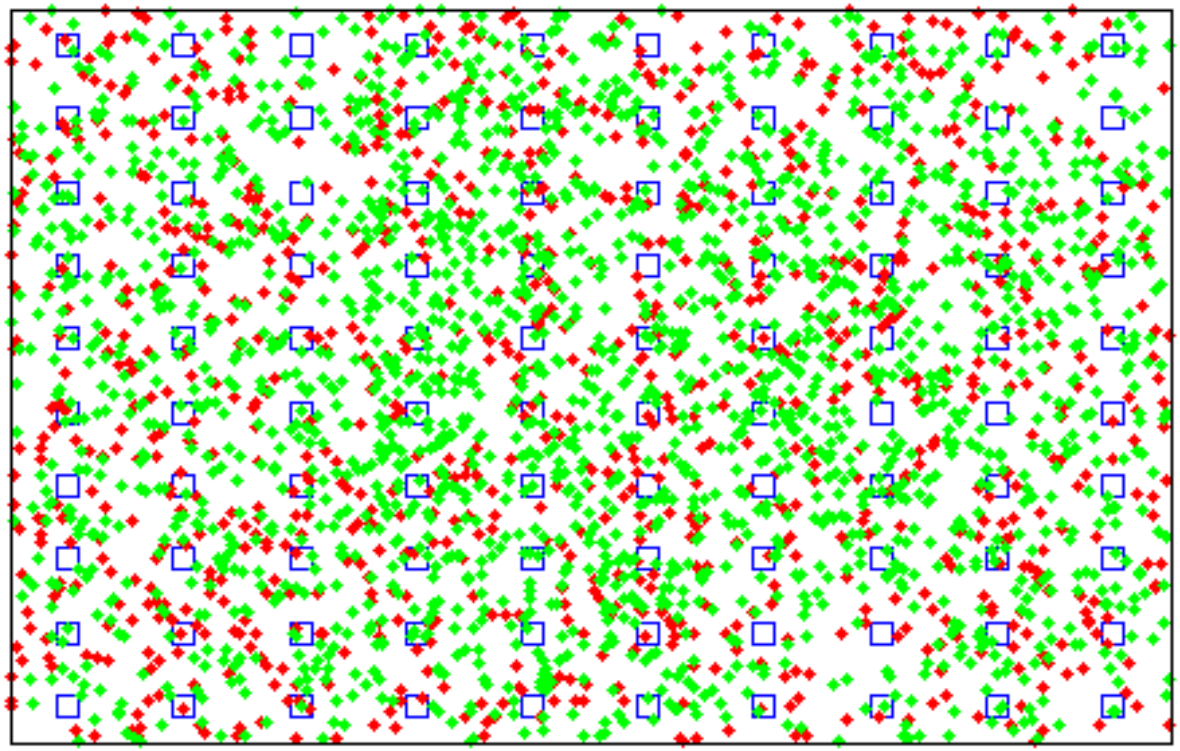
Simulation Results-2

- Distribution of network-1 users (1K)

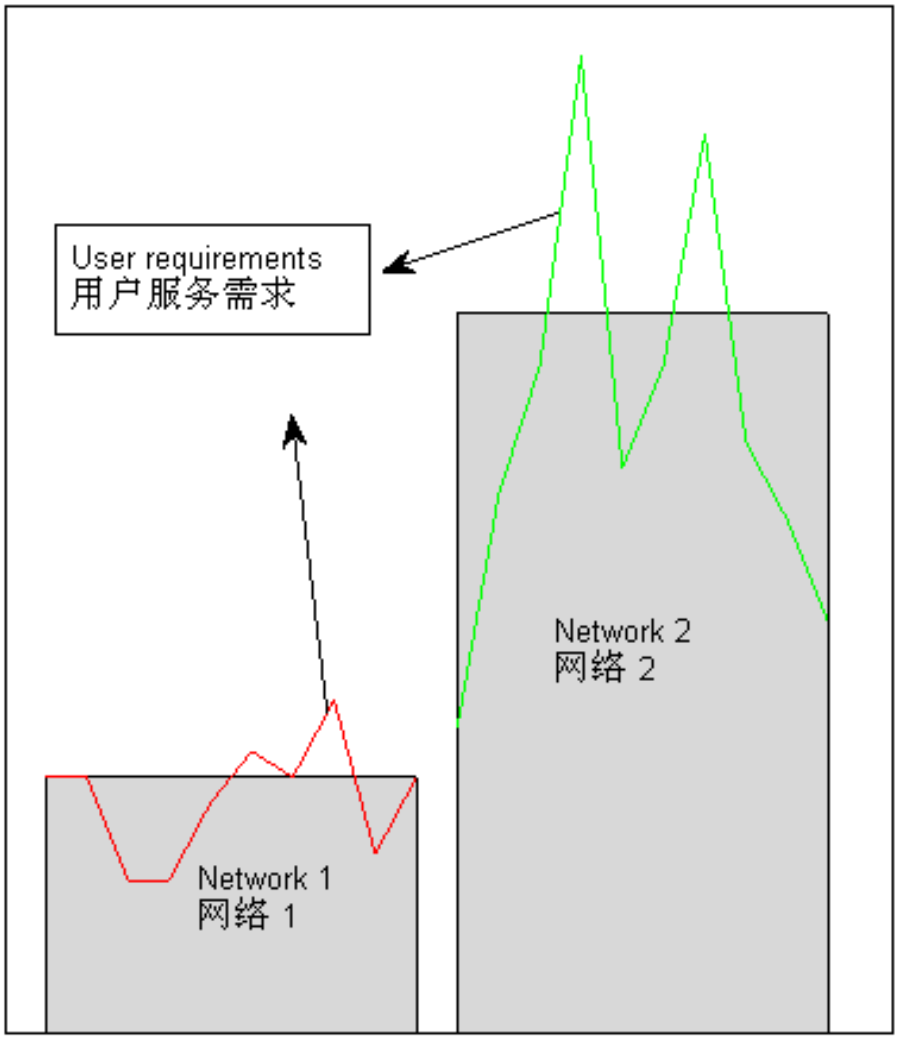


Simulation Results-3

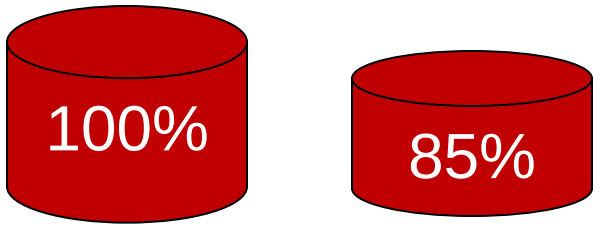
- Distribution of network-2 users (2K)



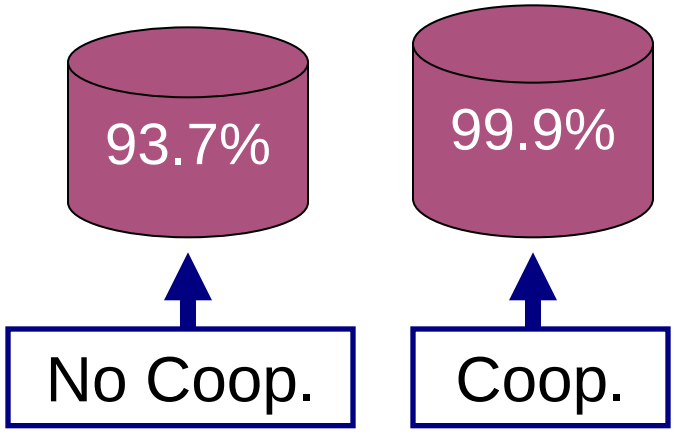
Simulation Results-4



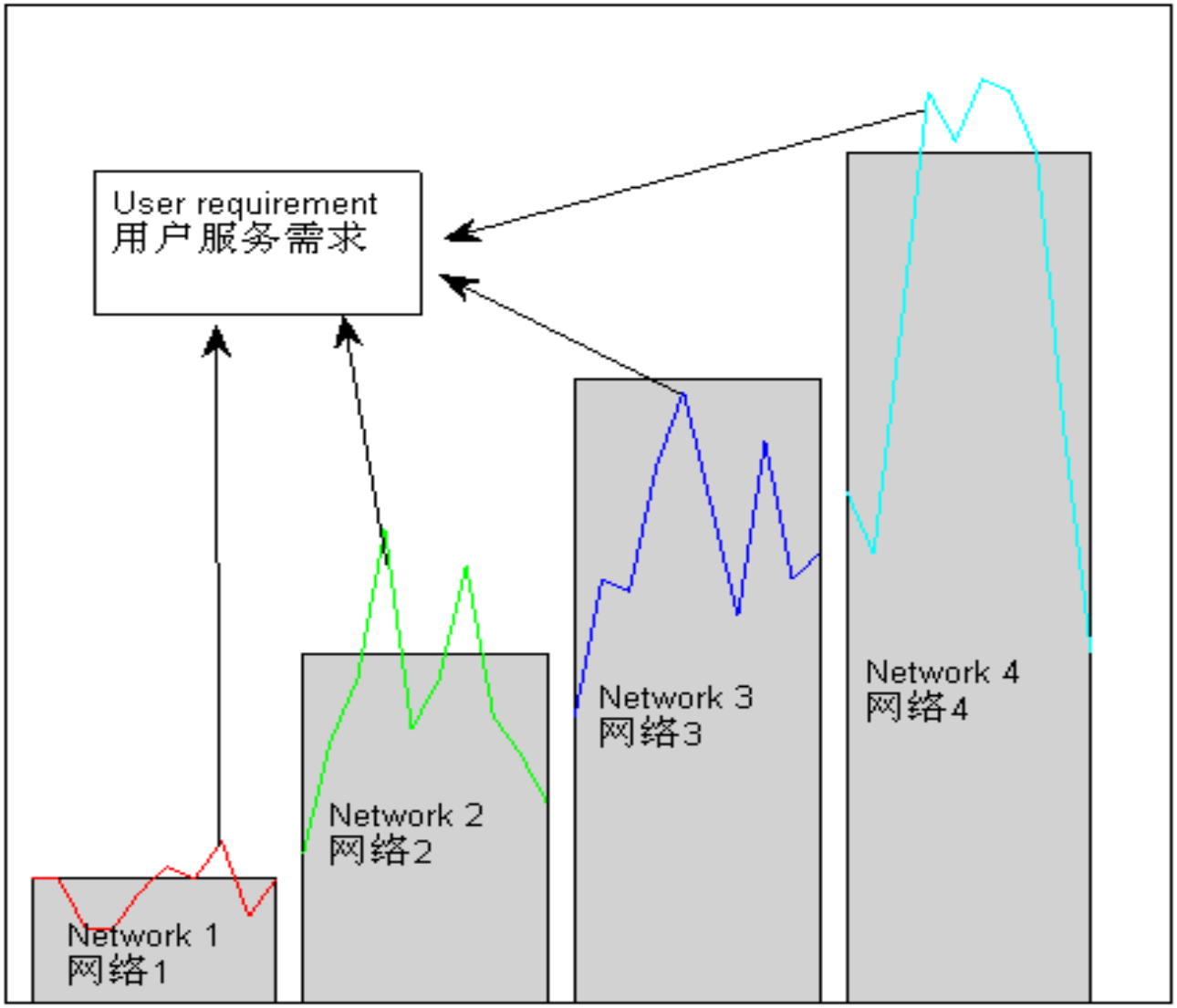
❖ **Energy Consumption**



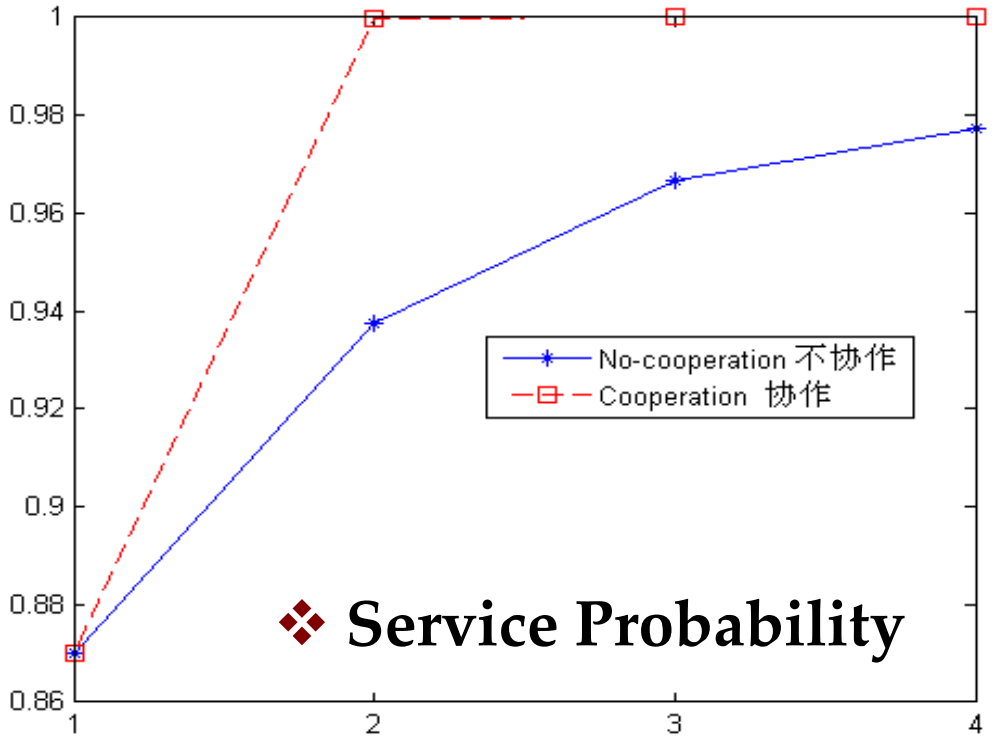
❖ **Service Probability**



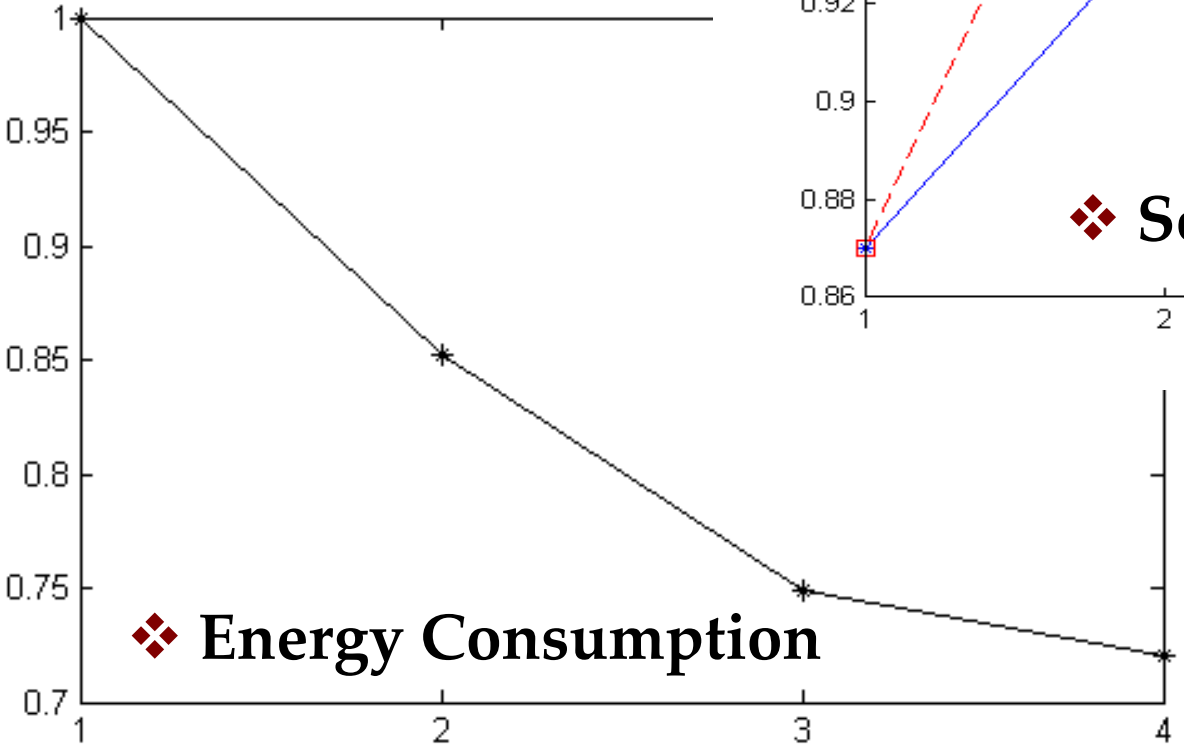
Simulation Results-5



Simulation Results-6



❖ Service Probability



❖ Energy Consumption

Better Green Services

Conclusions

- Cooperation in multi-hop wireless networks
  - Analytical model of multi-hop delay performance
  - Prediction based packet scheduling scheme
- Cooperation across multiple wireless networks
  - Less energy consumption **(cheap)**
  - Less greenhouse gas emission **(green)**
  - Less EMI and radiation pollution **(healthy)**
  - and better services **(happy :)**

Thank you very much for your comments and suggestions!

Dr. Yang Yang

Email: yang.yang@shrcwc.org

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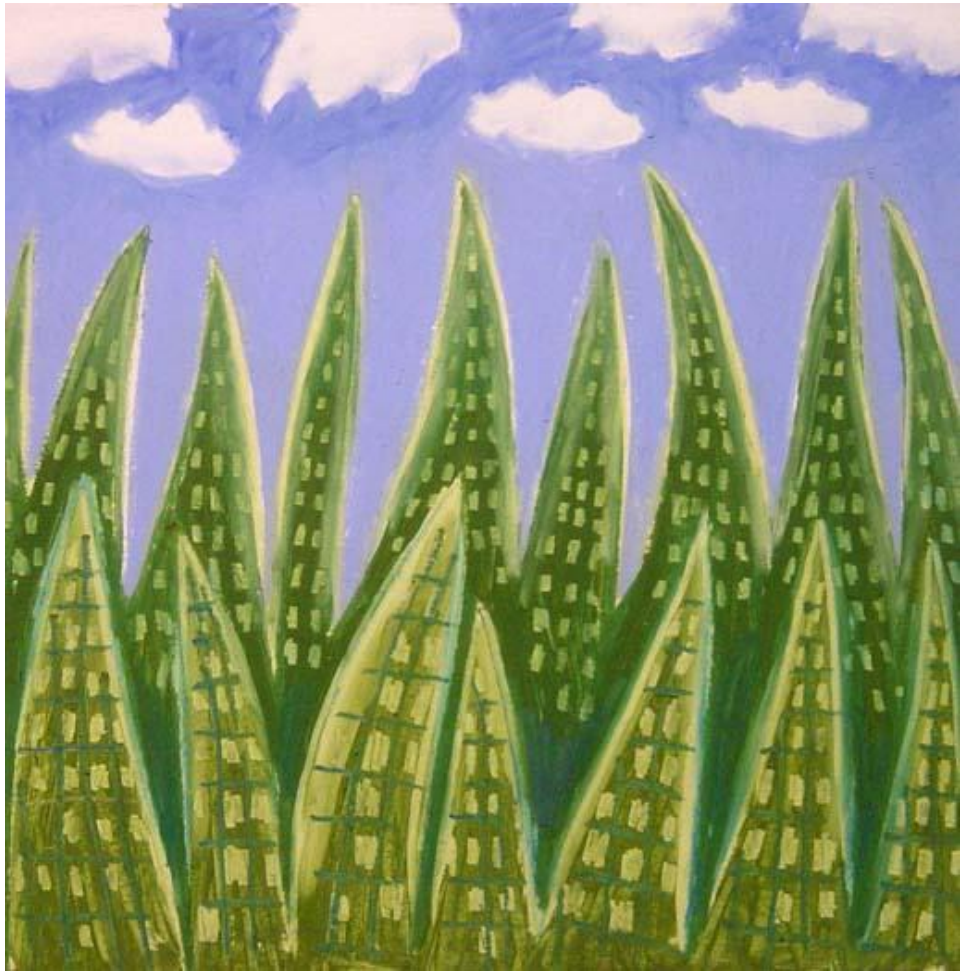

Green City, by Michael Pfleghaar