LTE Virtualization: from Theoretical Gain to Practical Solution

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ITC 23, September 6-8, 2011, San Francisco, USA

Motivation

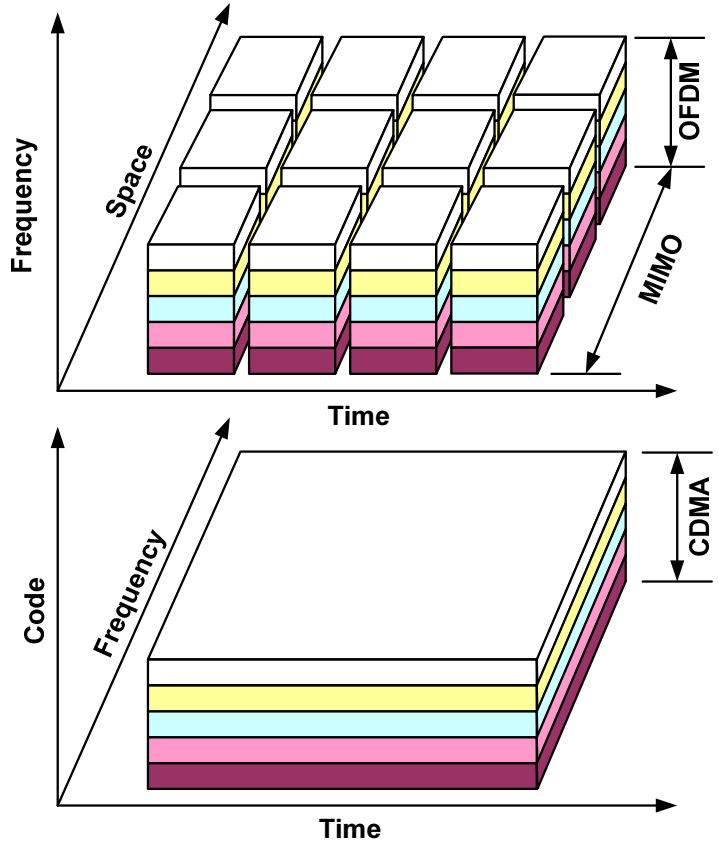
- Radio resources are scarce
- Instant traffic load of different operators can be different
- Resource sharing (spectrum sharing) can enhance the resource utilization and improve the system performance
- Spectrum sharing in the context of network virtualization
  - Wireless virtualization
  - LTE virtualization
- LTE virtualization makes sense
  - Reducing the CAPEX of operators
  - Improving system performance
  - Saving energy
  - OFDM-based PHY technique
  - ...

Outline

- Introduction to Network Virtualization
  - General Concept of Network Virtualization
  - Wireless Virtualization
  - Our Vision on LTE virtualization
- Analytical Investigation on Virtualization Gain
  - Analytical Approach based on Queue Theory
  - Validation by Simulation
- Multi-party Spectrum Sharing Model for LTE Virtualization
- Load Estimation based on Realtime Services
  - Idea → Improvement →Results
- Conclusion

Network Virtualization and Wireless Virtualization

- Network Virtualization: multiple virtual networks running on a common physical network
  - Abstraction, isolation, sharing ……
  - Node virtualization and link virtualization
  - E.g. 4WARD project [1]
- Wireless Virtualization
  - A nature extension from wired to wireless virtualization
  - Virtualization of the wireless resources on the air interface is one scheduling problem of Tx/Rx power, frequency, time, and code or space allocation, like well known wireless transmission strategies: FDMA, TDMA, CDMA and SDMA
  - Issue: the wireless links suffer more interference than the wired ones



Our Vision on LTE Virtualization

- The Virtual Operator (VO) of LTE Virtualization is different from the traditional MNVO
  - VO has the control of his network from end-to-end
  - VO has more flexibility of upgrading, expanding and tuning his network
  - VO pays less money to run a mobile network
  - .....
- Our solution focuses on the air interface of LTE
  - Spectrum sharing in the context of LTE virtualization
  - Revealing the potential advantage of LTE virtualization
  - Proposing solutions on some of the aspects for applying it
  - Hardware virtualization is out of our scope. See more [2]

Gain Analysis based on Queue Theory

- Starting from a FTP-only scenario to reveal the gain of LTE virtualization
  - FTP is best effort
  - One FTP connection can theoretically occupy the whole capacity of one cell
- M/G/1-PS can be employed to model this scenario
  - Each flow in the system has the ability to fully utilize the whole capacity
  - ***M*** requires the flow arrival follows a Poisson process with arrival rate λ
  - ***G*** means a generally distributed service time
  - ***1*** server applies the Processor Sharing (***PS***) discipline
- Then,
  - The expected sojourn time t (average FTP download time of a file size x) [3]

$$E_{M/G/1-PS}\{t\} = \frac{x}{C}\cdot\left(\frac{1}{1-\rho}\right) \quad \text{where,} \quad \rho = \frac{\lambda\cdot\bar{x}}{C}$$

  - If "n" virtual operators are sharing the spectrum in on cell, then the capacity C and arrival rate λ increase "n" times

$$\rho = \frac{n\cdot\lambda\cdot\bar{x}}{n\cdot C} = \frac{\lambda\cdot\bar{x}}{C}; \quad \Rightarrow \quad E_{M/G/1-PS}\{t\} = \frac{x}{n\cdot C}\cdot\left(\frac{1}{1-\rho}\right)$$

Validation by Simulation

- Temporary conclusion and questions
  - Large multiplexing gain can be obtained by the spectrum sharing between VOs
  - Question 1: does this hold for simulations?
  - Question 2: for LTE systems, each VoIP connection requires at least one PRB to transmit packets. If a lot of VoIP users are available, is this gain still obvious?

TABLE I
FTP DOWNLOADING

Parameter	Assumption
average file size $\bar{\chi}$	exponential distribution with mean of 5 [MB]
average IAT $1/\lambda$	exponential distribution

TABLE II
VOIP TRAFFIC MODEL

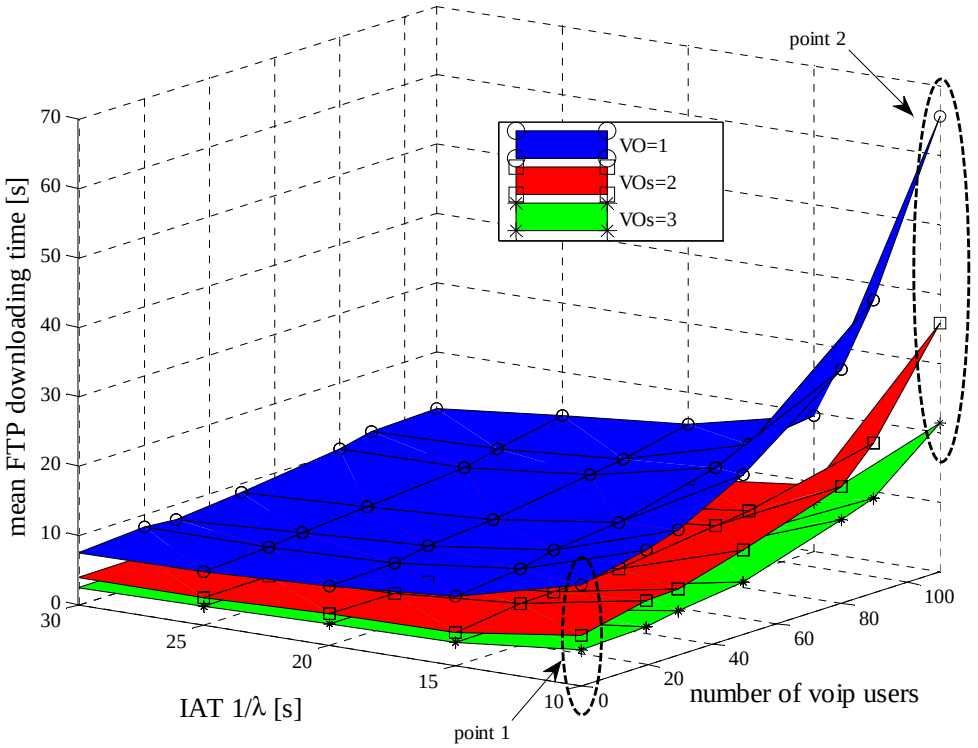
Parameter	Assumption
activity factor	0.5
talking time	exponential distribution with mean of 3 [s]
silence time	exponential distribution with mean of 3 [s]
call duration	complete run time
data packet size	40 [byte] every 20 [ms] during talking time
SID packet	20 [byte] every 160 [ms] during silence

TABLE III
SIMULATION MODELS

Parameter	Assumption
number of VO	1 to 3
eNBs in each VO	19 hexagonally in 3 tiers
sectors of each eNB	3
site-2-site distance	500 [m]
spectrum of each VO	5 MHz := 25 PRBs
total output power	20 [W] := 43 [dBm]
path loss model	COST 231
2D slow fading	20 m decorrelation distance
fast fading	Rosa Zheng model [12]
mobility model	reallocation of stationary users
traffic model	Table I and II
scheduling	VoIP-prioritized Round-Robin

Validation by Simulation cont.

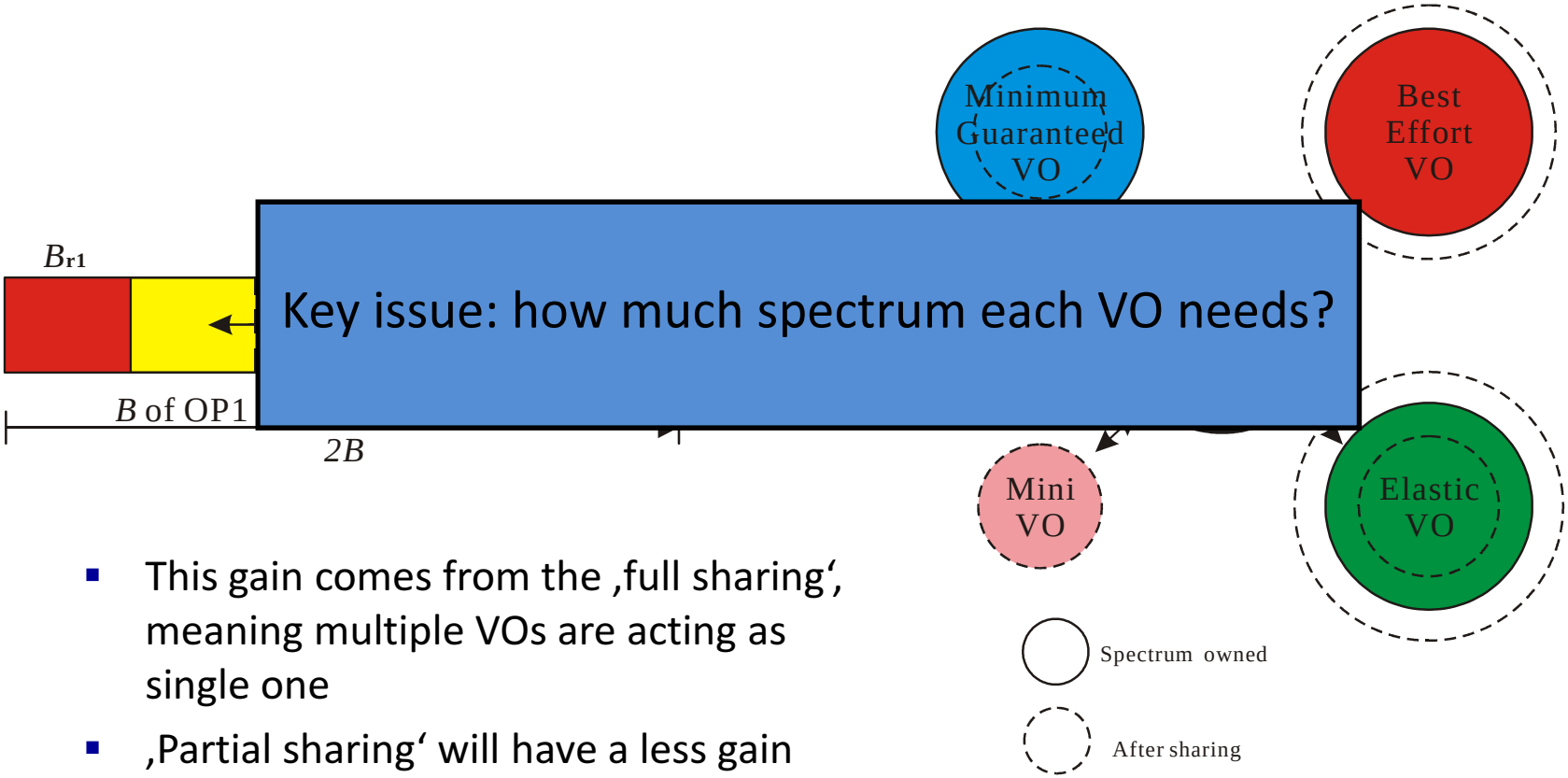
- The benchmark is the average FTP download time
- The results from simulations are closely matched to analytical analysis
- Even many VoIP users are in the system, the gain from spectrum sharing is still obvious



Points	VOs	M/G/1-PS	Simulation
point 1 FTP only	$O = 1 \rightarrow 2$	50%	1-5.91s/11.91s = 51.4%
	$O = 1 \rightarrow 3$	66.7%	1-3.92s/11.91s = 67.1%
point 2 FTP and VoIP=100	$O = 1 \rightarrow 2$	50%	1-35.9s/66.71s = 46.2%
	$O = 1 \rightarrow 3$	66.7%	1-21.5s/65.71s = 67.8%

Multi-party Spectrum Sharing Model for LTE Virtualization

- Sharing model:
  - Illustration of the spectrum sharing among multiple VOs
  - Different VOs may have different strategies



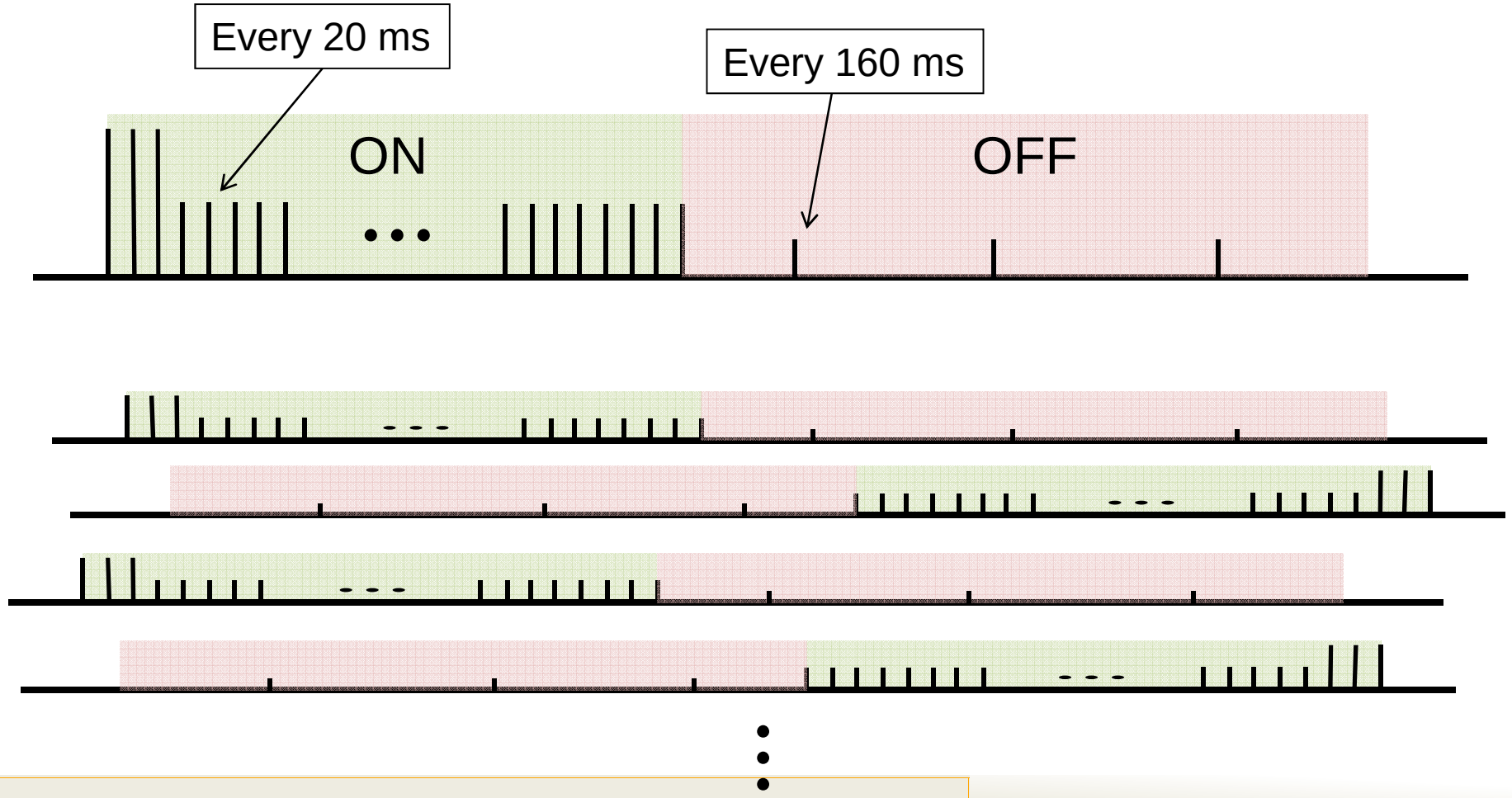
- This gain comes from the ‚full sharing', meaning multiple VOs are acting as single one
- ‚Partial sharing' will have a less gain

Load Estimation based on Real-time Services: Idea

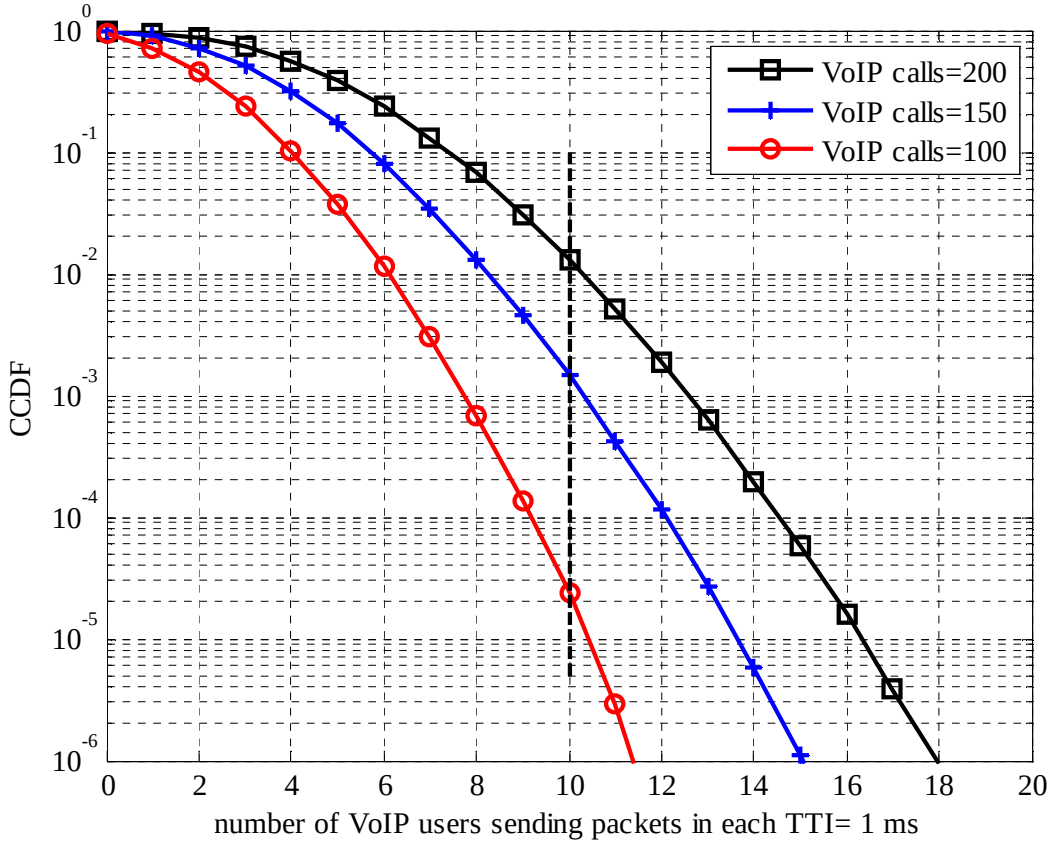
- Real time services; GBR; CBR .... normally require constant bit rates
- Real time services should have higher priority than non-real time services to guarantee QoS
- VoIP is one common but one of the most services of operators
- idea
  - Number VoIP users →
  - Number of active VoIP users →
  - Number of VoIP packets →
  - Required BW (PRBs) →
  - Load estimation (including some margin) →
  - Spectrum Sharing

Traffic Model of VoIP

- Length of ON and OFF periods follows an exponential distribution with a same mean



Load Estimation based on each TTI = 1ms

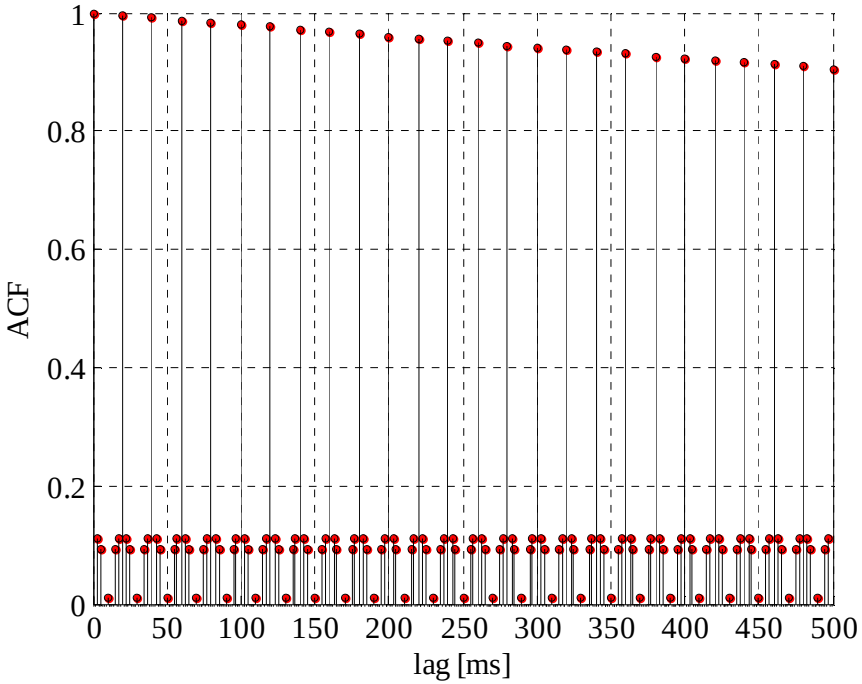


Number of active VoIP users in each TTI = 1ms

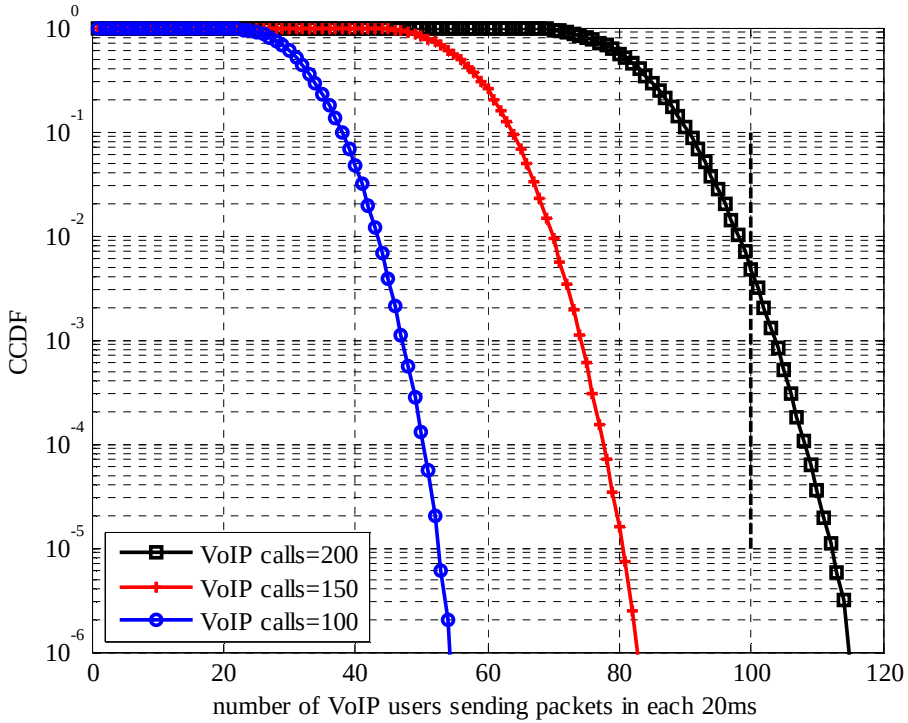
→ 10 user/ms can cover > 99% ?

Load Estimation based on Real-time Services: Improving

- Improving based on 20ms estimation
  - From the traffic model of VoIP, 1 packet every 20 ms in ON period
  - Checking the traffic characteristics in every 20ms
  - Load estimation can be more accurate



Autocorrelation of user traffic for 200 VoIP calls
Shows a strong correlation every 20 ms

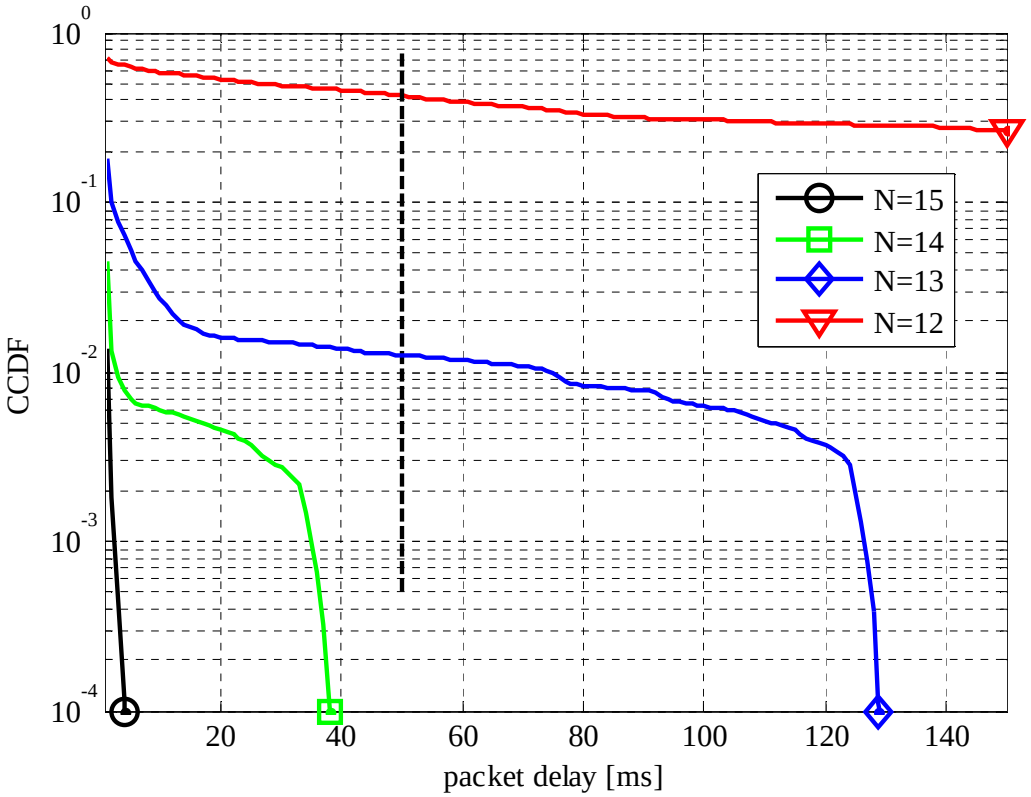


Traffic load in every 20ms:
100 users/20ms = 5 users/ms is enough!

Load Estimation based on Real-time Services: Results

- Each active user has one packet of 40 Bytes
- In our scenario, each 40 byte packet averagely requires 2-3 PRBs to transmit
- Packet delay is selected as the benchmark, and 50 ms is the delay budget

- 13-14 PRBs are enough to support the data transmission of 200 VoIP calls, but this number is scenario-speicific
- Spared PRBs can be shared between different VOs



Validation of load estimation
Delay peformance of 200 VoIP calls
N: number of PRBs reserved

Conclusion and Outlook

- Large multiplexing gain can be obtained via the spectrum sharing of LTE virtualization
  - Analytical observation
  - Simulative validation
- Reasonable spectrum sharing model and strategies are necessary
- Load estimation is the key issue for the success of the spectrum sharing
  - The load estimation based on the real time traffic model is accurate, easy and insensitive to the parameters
- Further works
  - Partially overlapping cell scenario
  - Heterogeneous traffic models

THANK YOU!

ANY QUESTION??

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