Analytic capacity estimation for semi-persistent VoIP traffic scheduling in LTE

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FFV Workshop 19.10.2012

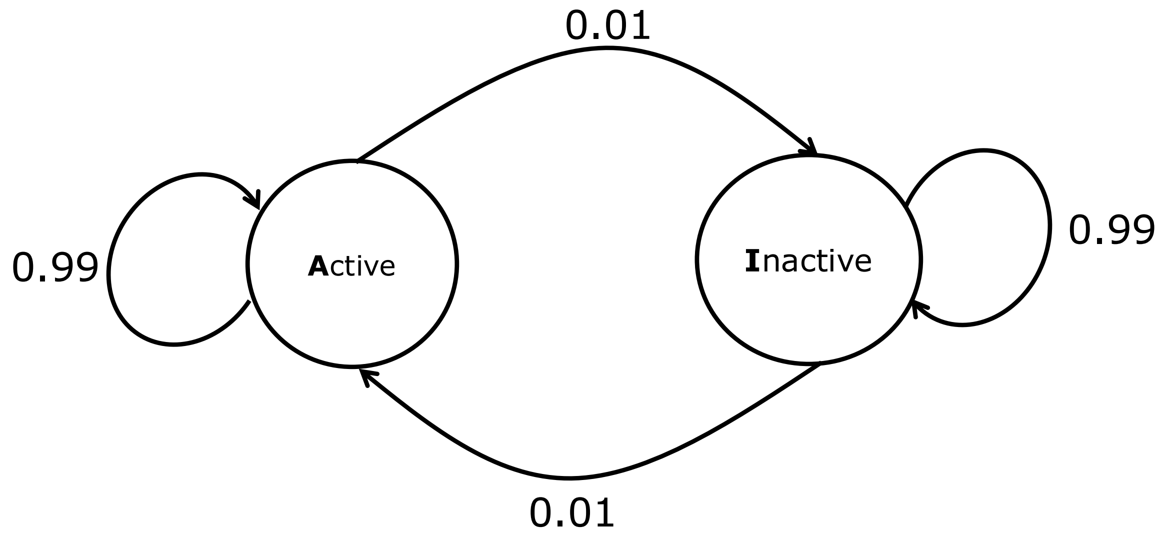
ComNets - TUHH

Technische Universität Hamburg-Harburg

Agenda

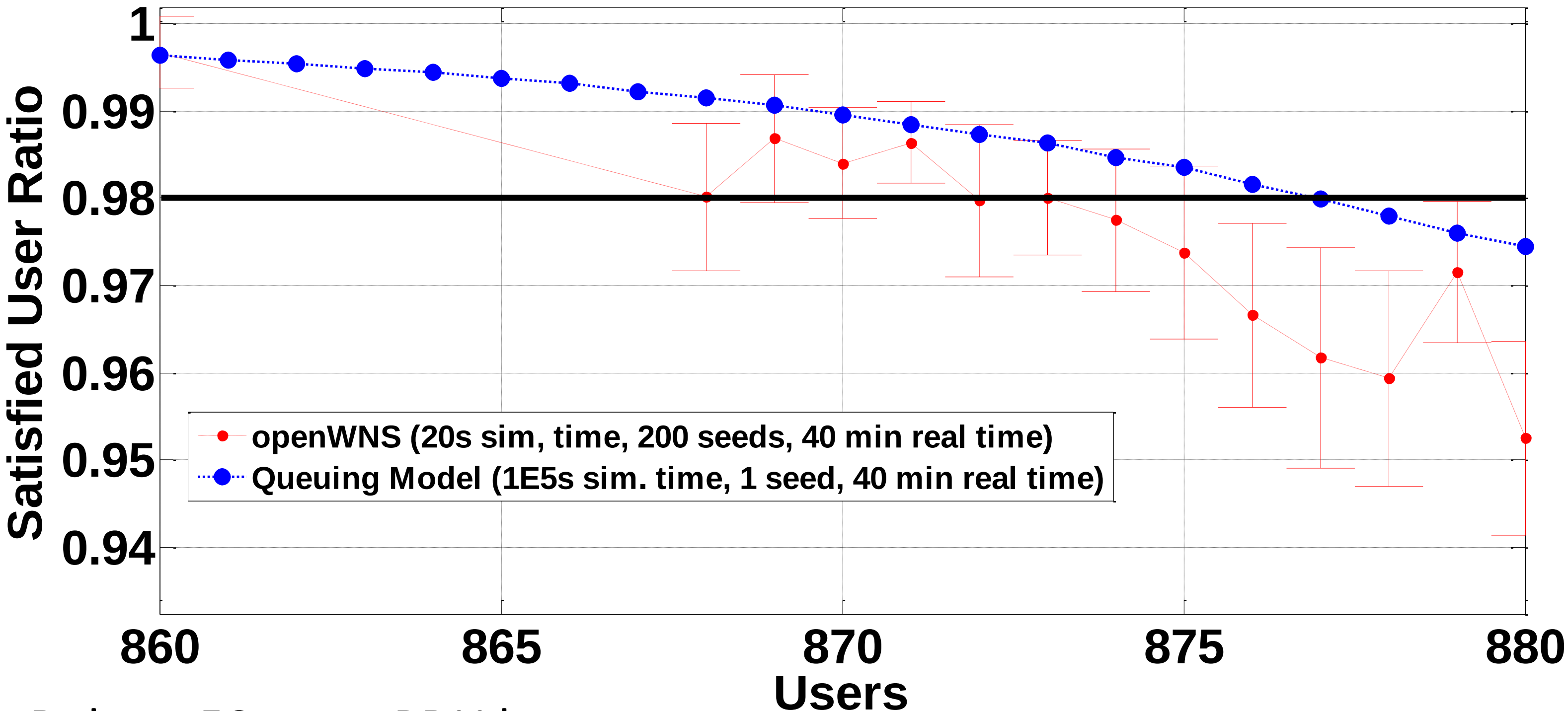
- IMT-Advanced VoIP Traffic Model
- LTE Simulation Results
- VoIP Queuing Model
- Analytic Results
- Summary, Conclusion & Outlook

IMT-Advanced VoIP Traffic Model



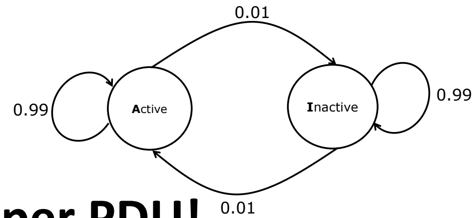
- Discrete time Markov model with two states (slot duration T = 20ms)
  - Active: transmit voice PDU every 20ms
  - Inactive: transmit silence indicator (SID) PDU every 160ms
- Semi-persistent scheduling:
  - reserve sufficient resources every 20ms (persistent)
  - schedule SID and HARQ retransmissions dynamically

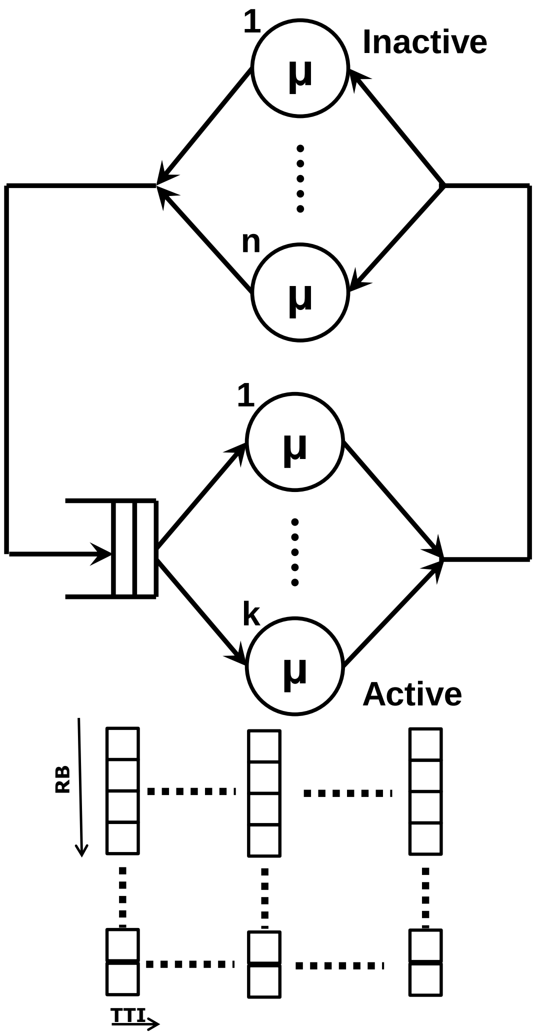
LTE Simulation Results



- Delay > 50ms => PDU lost
- Loss rate per node > 2% => User usatisfied
- More than 2% of users unsatisfied => Network capacity reached
- Upper bound: No transmission errors, one Resource Block (RB) per PDU, no SID PDUs

VoIP Queuing Model





- **Connection oriented (per call), not per PDU!**
- Discrete time (*T* = 20ms), closed queuing network with two nodes
  - Top: Inactive calls
  - **Bottom: Active calls**
- Fixed number of jobs *n*: VoIP users
- $\mu = 0.5s^{-1}$ (from VoIP traffic model parameters)
- *n* servers at top node => never wait
- *k* servers at bottom node
  - RBs in 20ms VoIP inter-arrival time (VoIP-IAT)
- Performance parameters:
  - Waiting probability P(x > k)
  - Waiting time distribution P(t > 50ms)

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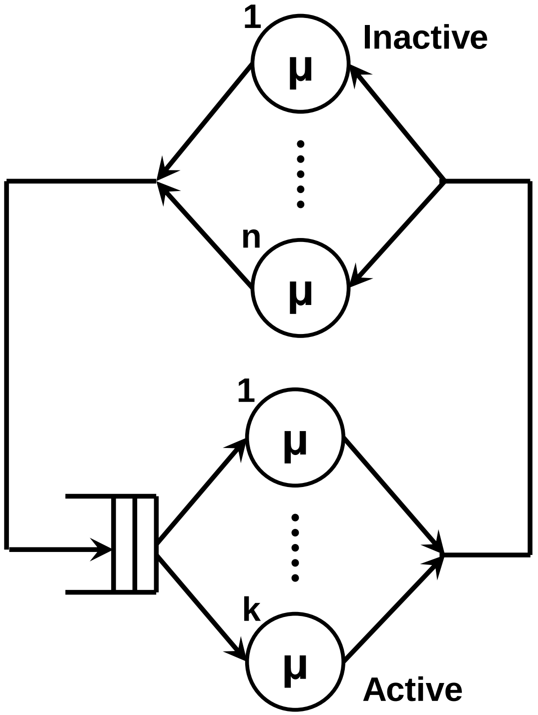
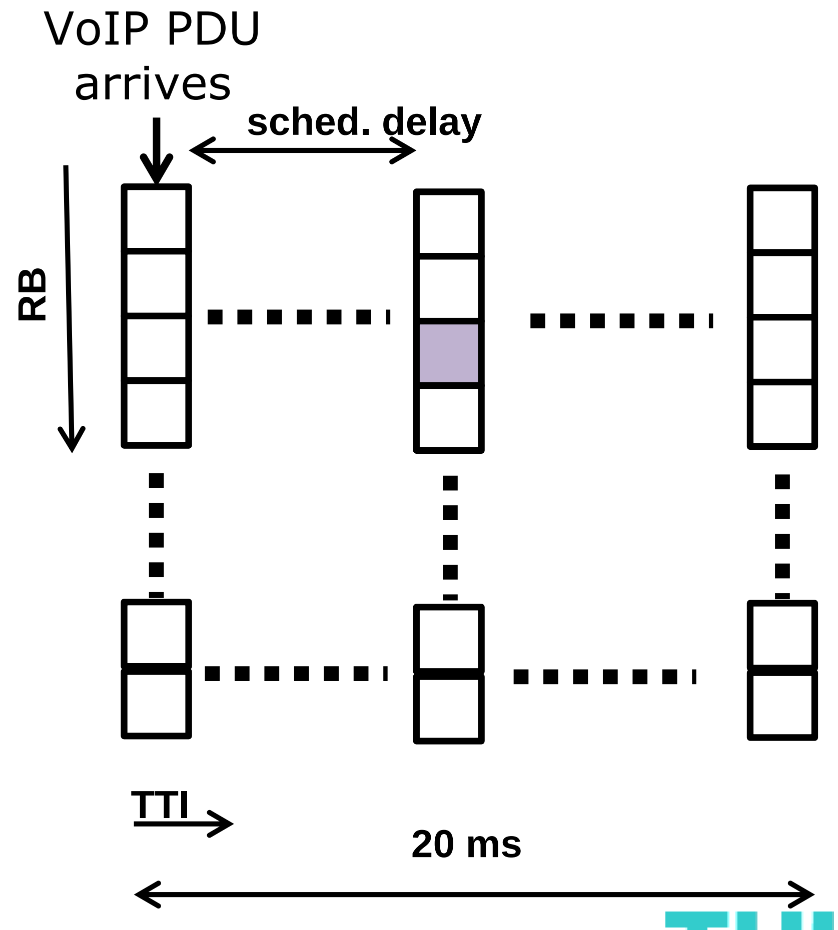
VoIP Queuing Model





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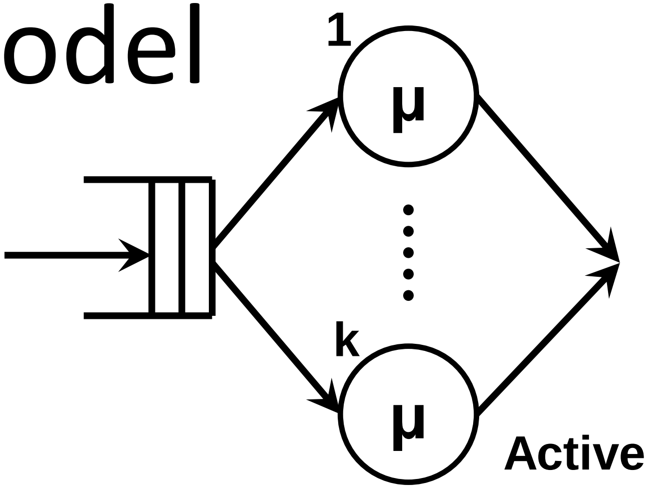
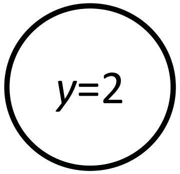


What is the number of active calls *x*?

- *x* is the number of active calls at time *t*
- *y* is the number of active calls at time *t*-*T*
- Each user changes state with p = 0.01



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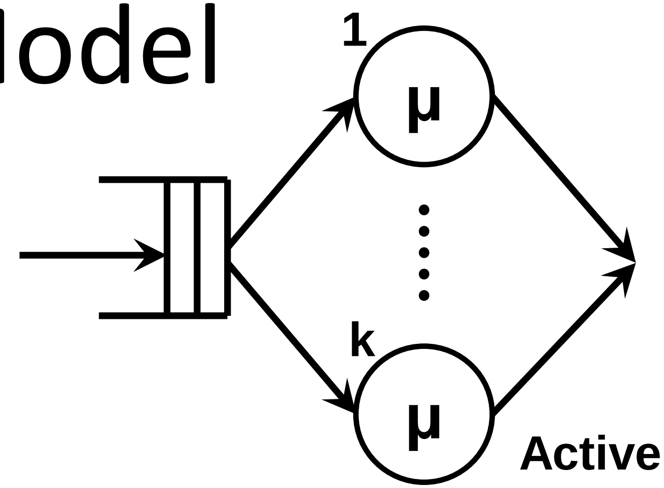
n=6

VoIP Queuing Model



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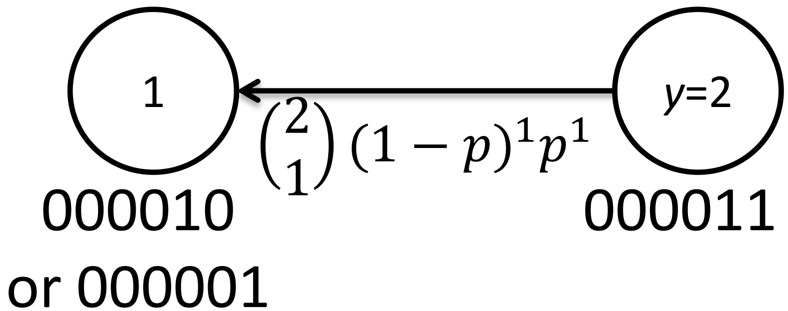

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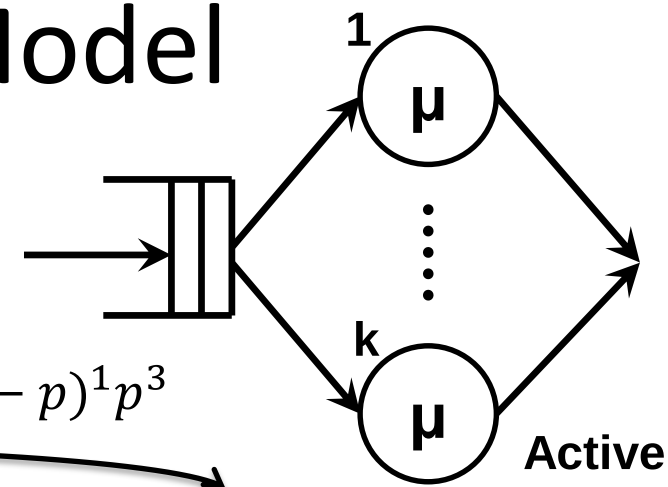

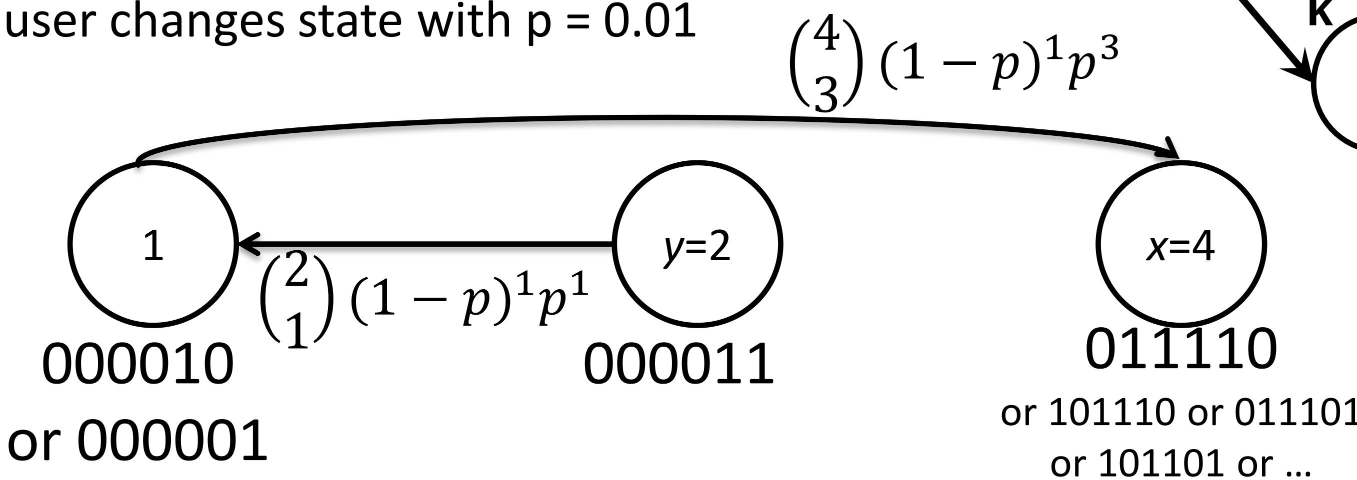

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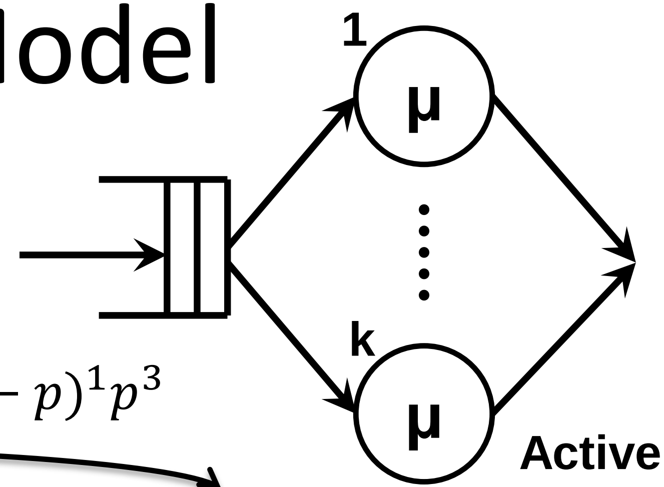
VoIP Queuing Model



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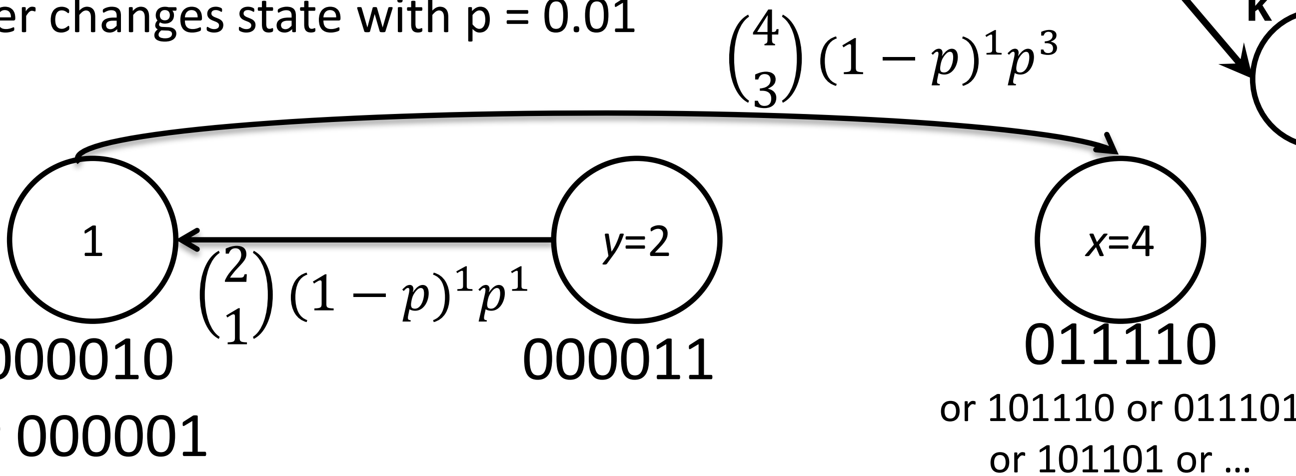

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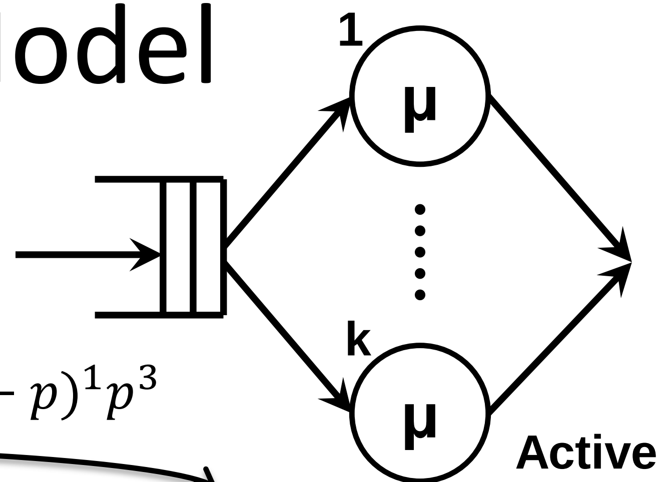
- *a(x|n-y), d(x|*min*(k,y))*: arrivals/departures distributed Binomially *B(x|i,p)*

VoIP Queuing Model



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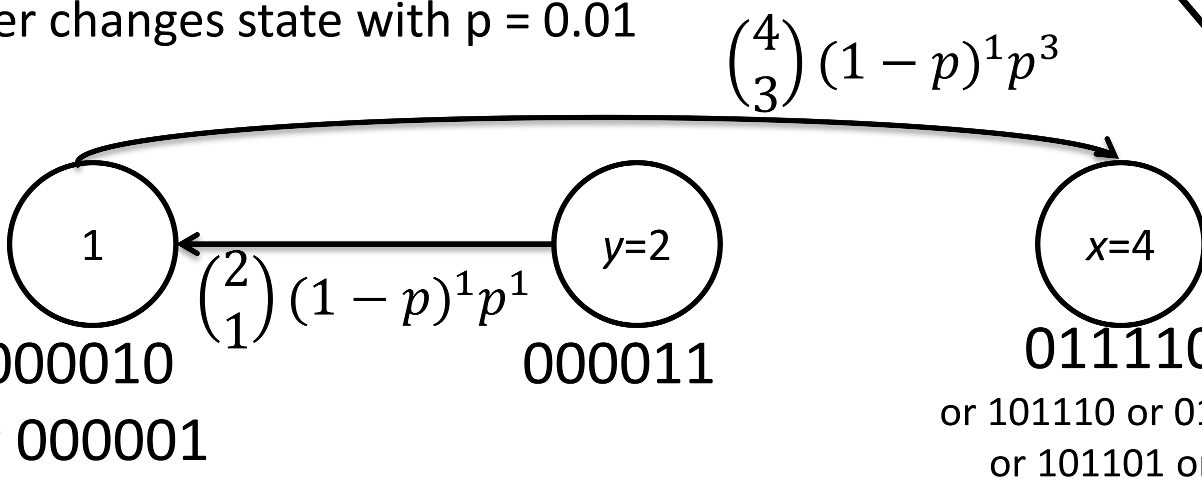

n=6

- *a(x|n-y), d(x|*min*(k,y))*: arrivals/departures distributed Binomially *B(x|i,p)*
- Markovian transition probabilities:
  - $P(x|y) = \delta(x-y) * d(-x|\min(k,y)) * a(x|n-y)$
  - Transition matrix ***P***
  - Solve $\pi(x)\boldsymbol{P} = \pi(x)$

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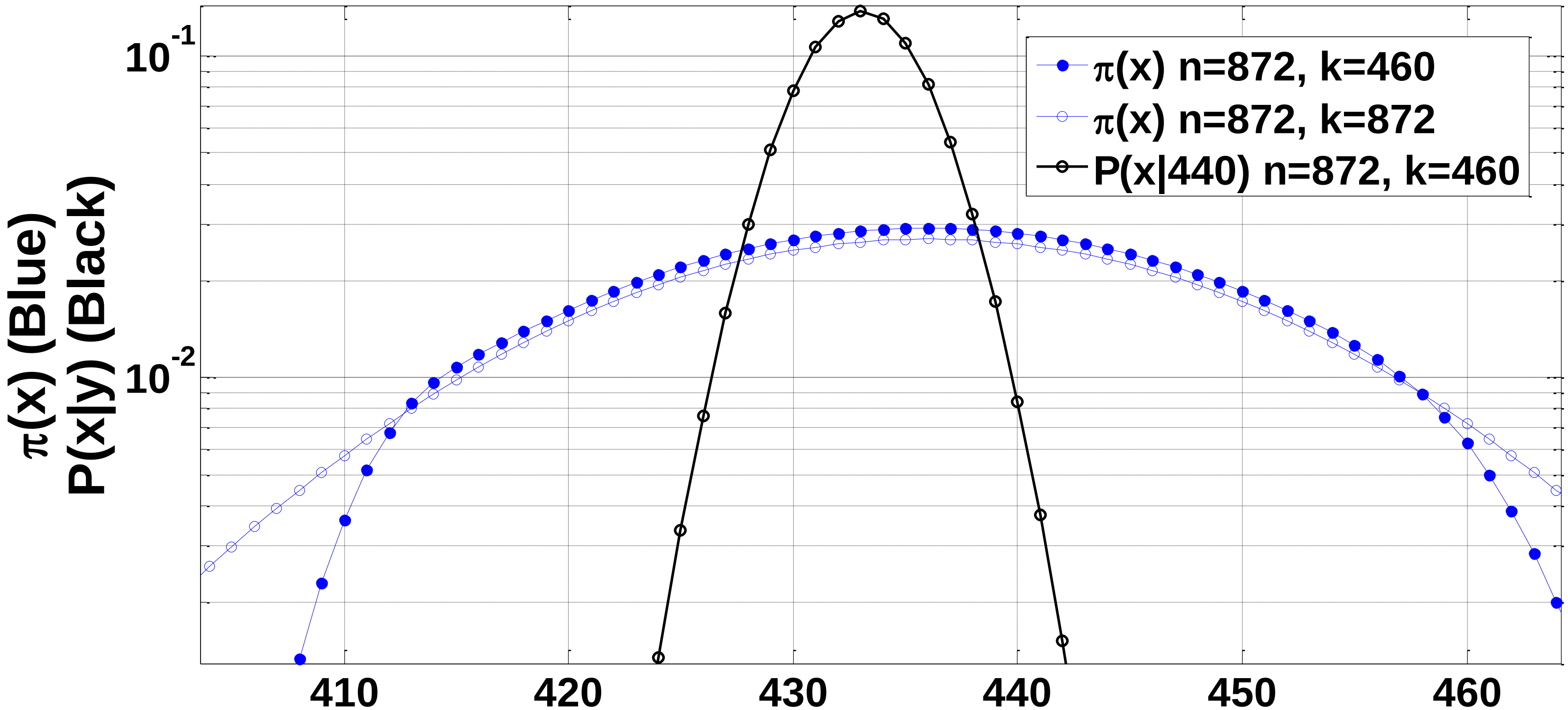
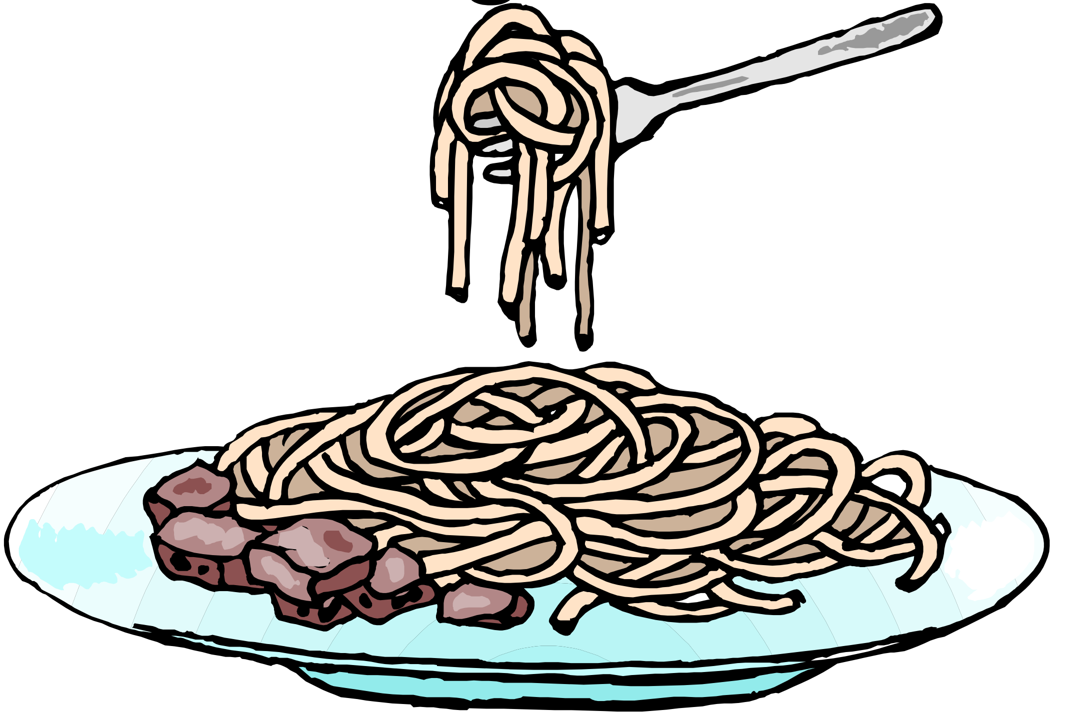
VoIP Queuing Model



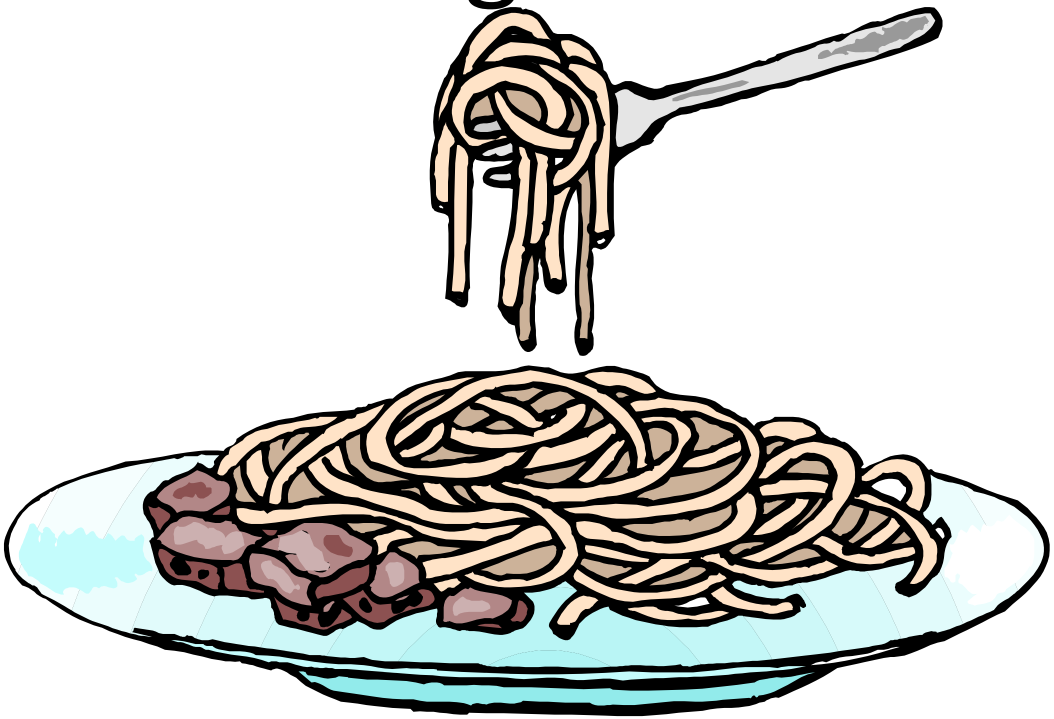
- *x* follows Binomial distribution *B(x|n, 0.5)* if *n = k*
- Extremely low probabilities
  - For most states *x*
  - For high transition distances |*y* – *x*|

VoIP Queuing Model: Delay



No PASTA served today!

VoIP Queuing Model: Delay



No PASTA served today!

PASTA: **P**oisson **A**rrivals **S**ee **T**ime **A**verages

=> Arrivals not Poisson, they do not "see" $\pi(x)$

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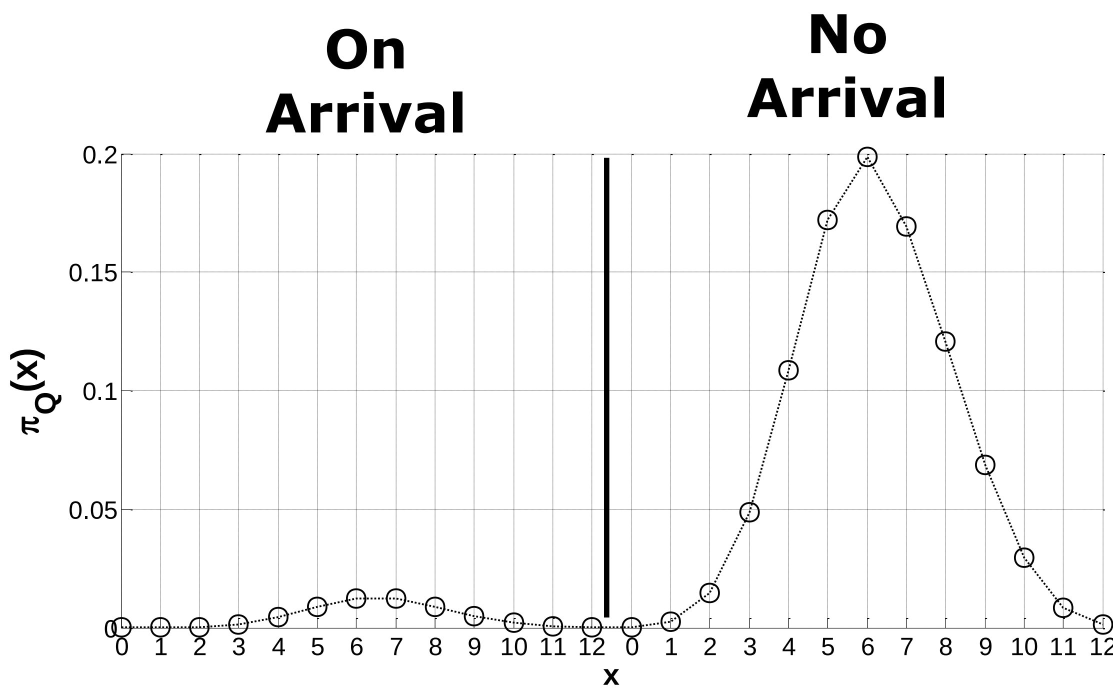
VoIP Queuing Model: Delay

Determine active call distribution **on arrival**

- Transition matrix **P** does not have this information: **7 + 3 – 4 = 6 = 7 + 0 – 1**
- Embedded Markov chain:
  - $\boldsymbol{Q} = \left(\begin{array}{c|c} \boldsymbol{P}_{a>0} & \boldsymbol{P}_{a=0} \\ \hline \boldsymbol{P}_{a>0} & \boldsymbol{P}_{a=0} \end{array}\right)$
  - Solve $\pi_{\boldsymbol{Q}}(x)\boldsymbol{Q} = \pi_{\boldsymbol{Q}}(x)$
  - $\pi_{\boldsymbol{Q},a>0}(x)$: Distribution on arrival



n = 12; k = 7; p=0.01

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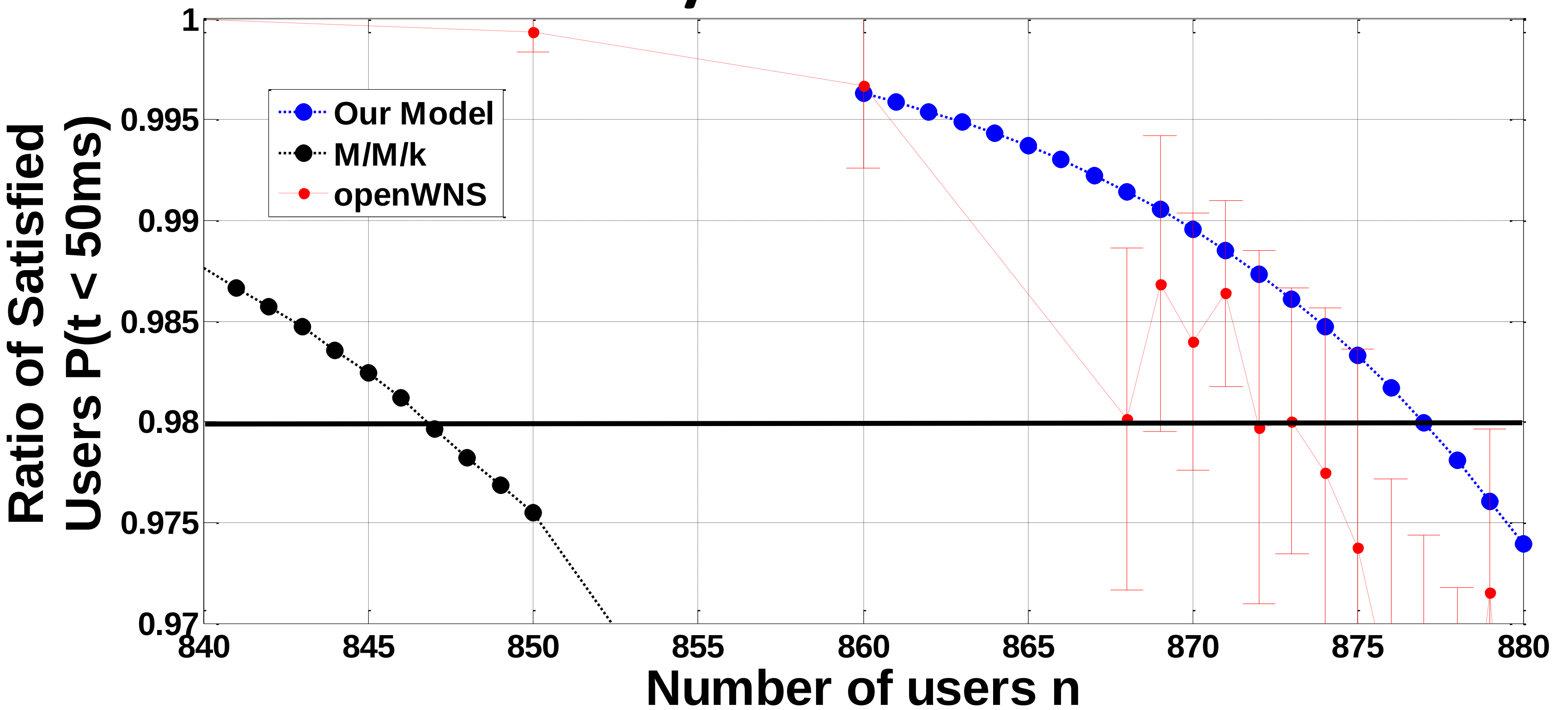
VoIP Queuing Model: Delay

x is after the arrival, what was the state *y* before?

- $\pi^{-}_{\mathbf{Q},a>0}(y) = \pi_{\mathbf{Q},a>0}(x)\mathbf{Q}^{-1}_{a>0}$ ← Numerically inaccurate if *n > 400* for double precision floating point operations
- Calculate distribution *q(x)* of "position in arriving batch" of marked job
  - Based on [1]
  - Extended to depend on state *y*
- Departure matrix **D:** $D(x|y) = \delta(x-y) * d(-x|y)$
- Waiting time distribution: $P(t > \tau \cdot 20ms) = 1 - \sum_{i=0}^{k} q(x=i)\mathbf{D}^{\tau}$

[1]: Bruneel, H.L. "Buffers with stochastic output interruptions" in Electronics Letters Vol. 19, 1983

Analytic Results



- k = 460 (23RBs in freq. domain, 20 TTIs in time domain)
- 9 seconds to calculate one result
- $n\rho = (n \cdot 0.5 \cdot 0.5s^{-1})/(k \cdot 0.5s^{-1})$

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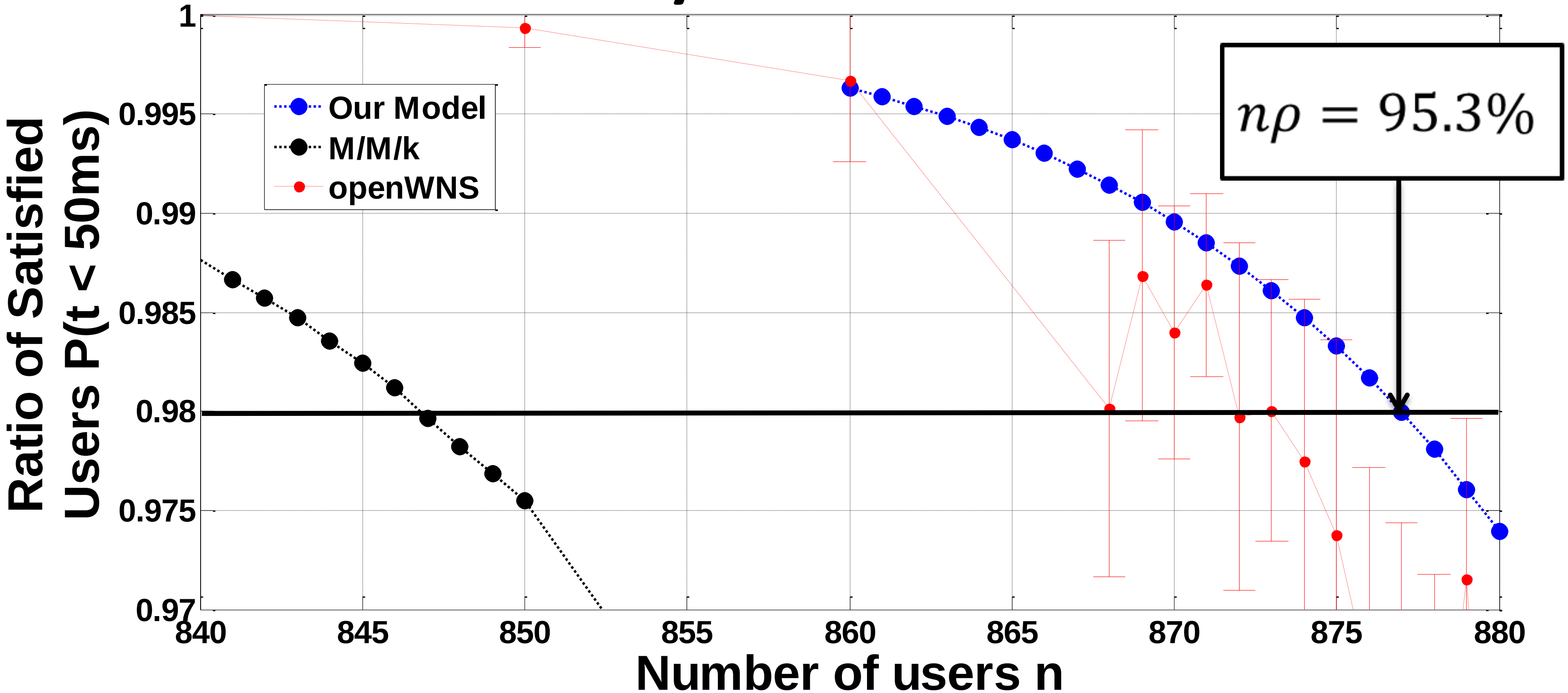

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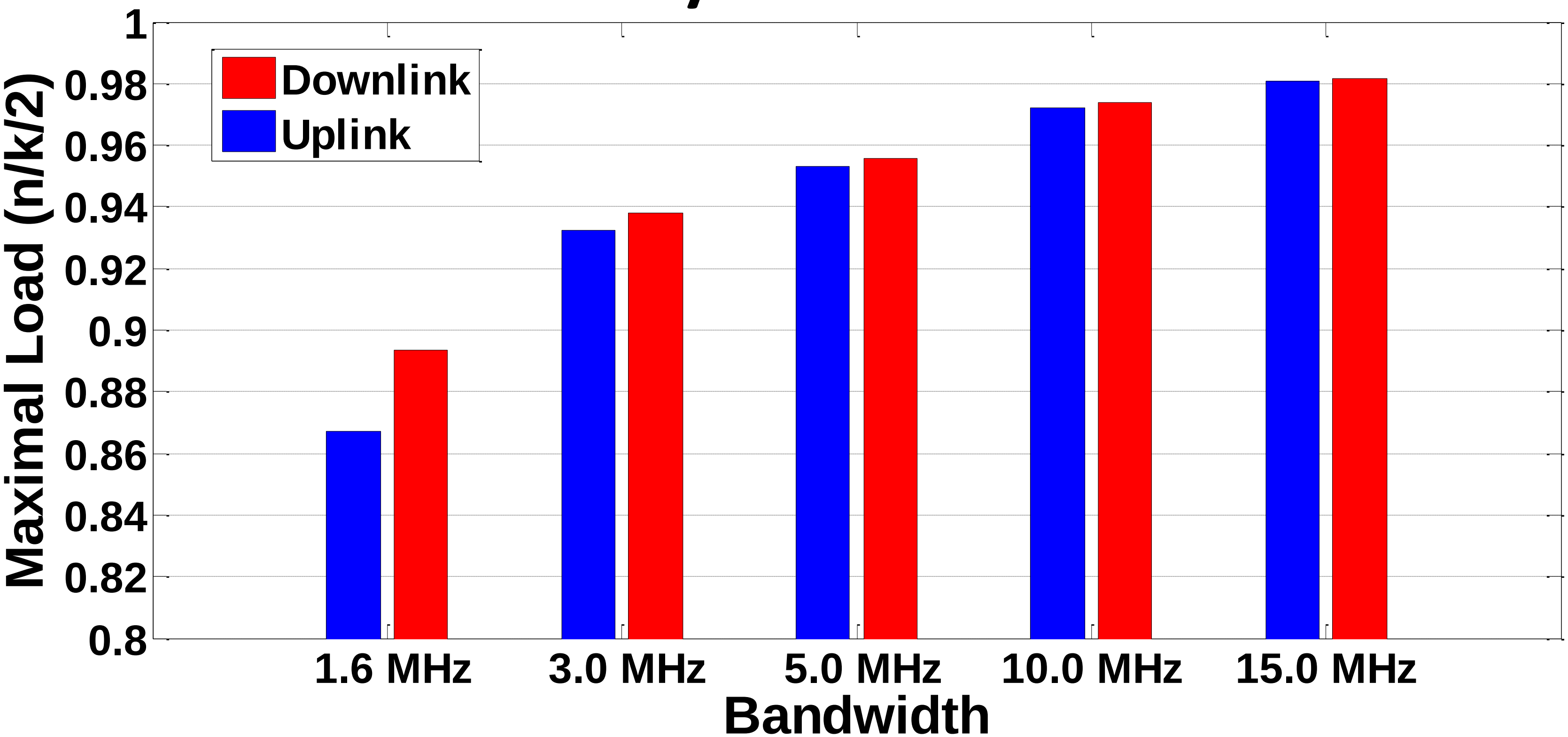

- 2 or 4 RBs reserved for control channel in uplink
- Trunking gain increases as expected

Summary, Conclusion & Outlook

Summary

- An analytic queuing model for upper bound VoIP capacity in LTE was developed

Conclusions

- Trunking gain increases as the number of available OFDMA resources for VoIP increases
- Analytic queuing models can be used to quickly evaluate VoIP performance

Outlook

- Introduce Modulation & Coding Schemes (job classes)
- Influence of modeling assumptions

THANK YOU FOR YOUR ATTENTION.