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

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ComNets - TUHH
Agenda

• IMT-Advanced VoIP Traffic Model
• LTE Simulation Results
• VoIP Queuing Model
• Analytic Results
• Summary, Conclusion & Outlook
Analytic capacity estimation for semi-persistent VoIP traffic scheduling in LTE

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

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

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LTE Simulation Results

22.10.2012
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VoIP Queuing Model

- **Connection oriented (per call), not per PDU!**
- Discrete time ($T = 20$ms), 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 $P(t > 50$ms$)$
Analytic capacity estimation for semi-persistent VoIP traffic scheduling in LTE

**VoIP Queuing Model**

- **Inactive** state: 
  - 
  - 
  - 
- **Active** state: 
  - 
  - 
  - 

VoIP PDU arrives

**sched. delay**

**RB**

**TTI**

20 ms
VoIP Queuing Model

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 $p = 0.01$

$n=6$

$y=2$

000011
VoIP Queuing Model

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 $p = 0.01$

$$n=6 \quad \text{or} \quad 000001$$
VoIP Queuing Model

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- Each user changes state with $p = 0.01$

$$n=6$$

or 000001

$$(\binom{4}{3})(1-p)^1p^3$$

$$(\binom{2}{1})(1-p)^1p^1$$
VoIP Queuing Model

What is the number of active calls $x$?

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

$n=6$

- $a(x|n-y)$, $d(x|\min(k,y))$: arrivals/departures distributed Binomially $B(x|i,p)$
VoIP Queuing Model

What is the number of active calls $x$?
- $x$ is the number of active calls at time $t$
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What is the number of active calls $x$?

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

$\mu$

1

$\mu$

Active

$\mu$

1

$\mu$

Active

$\mu$

1

$\mu$

Active

\[
\begin{align*}
(4)_{3} & (1 - p)^{1} p^{3} \\
(2)_{1} (1 - p)^{1} p^{1} & \quad (0)_{1} (1 - p)^{0} p^{0} \\
000010 & \quad 000011 \\
\end{align*}
\]

$n = 6$

or 000001

or 011110 or 011101

or 101110 or 011101 or ...

\[
\begin{align*}
(4)_{3} & (1 - p)^{1} p^{3} \\
(2)_{1} (1 - p)^{1} p^{1} & \quad (0)_{1} (1 - p)^{0} p^{0} \\
000010 & \quad 000011 \\
\end{align*}
\]
Analytic capacity estimation for semi-persistent VoIP traffic scheduling in LTE

VoIP Queuing Model

- $x$ follows Binomial distribution $B(x \mid n, 0.5)$ 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: Poisson Arrivals See Time Averages

=> Arrivals not Poisson, they do not “see” $\pi(x)$
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:
  
  $Q = \begin{pmatrix} P_{a>0} & P_{a=0} \\ P_{a>0} & P_{a=0} \end{pmatrix}$

- Solve $\pi_Q(x)Q = \pi_Q(x)$
- $\pi_{Q,a>0}(x)$: Distribution on arrival

$n = 12; k = 7; p=0.01$
VoIP Queuing Model: Delay

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

- \( \pi_{Q,a>0}^{-}(y) = \pi_{Q,a>0}^{-1}(x)Q_{a>0}^{-1} \)
- 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: \( P(t > \tau \cdot 20ms) = 1 - \sum_{i=0}^{k} q(x = i)D^\tau \)

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

Analytic Results

- $k = 460$ (23RBs in freq. domain, 20 TTIs in time domain)
- 9 seconds to calculate one result
- $n\rho = (n \cdot 0.5 \cdot 0.5s^{-1})/(k \cdot 0.5s^{-1})$
Analytic capacity estimation for semi-persistent VoIP traffic scheduling in LTE

Analytic Results

- $k = 460$ (23RBs in freq. domain, 20 TTIs in time domain)
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$n\rho = 95.3\%$
Analytic capacity estimation for semi-persistent VoIP traffic scheduling in LTE

- 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.