Modeling and Performance Analysis of Public Safety Wireless Networks

Jiaqing (James) Song
jsong@cs.sfu.ca

Communication Networks Laboratory
http://www.ensc.sfu.ca/cnl
Simon Fraser University

communication networks laboratory

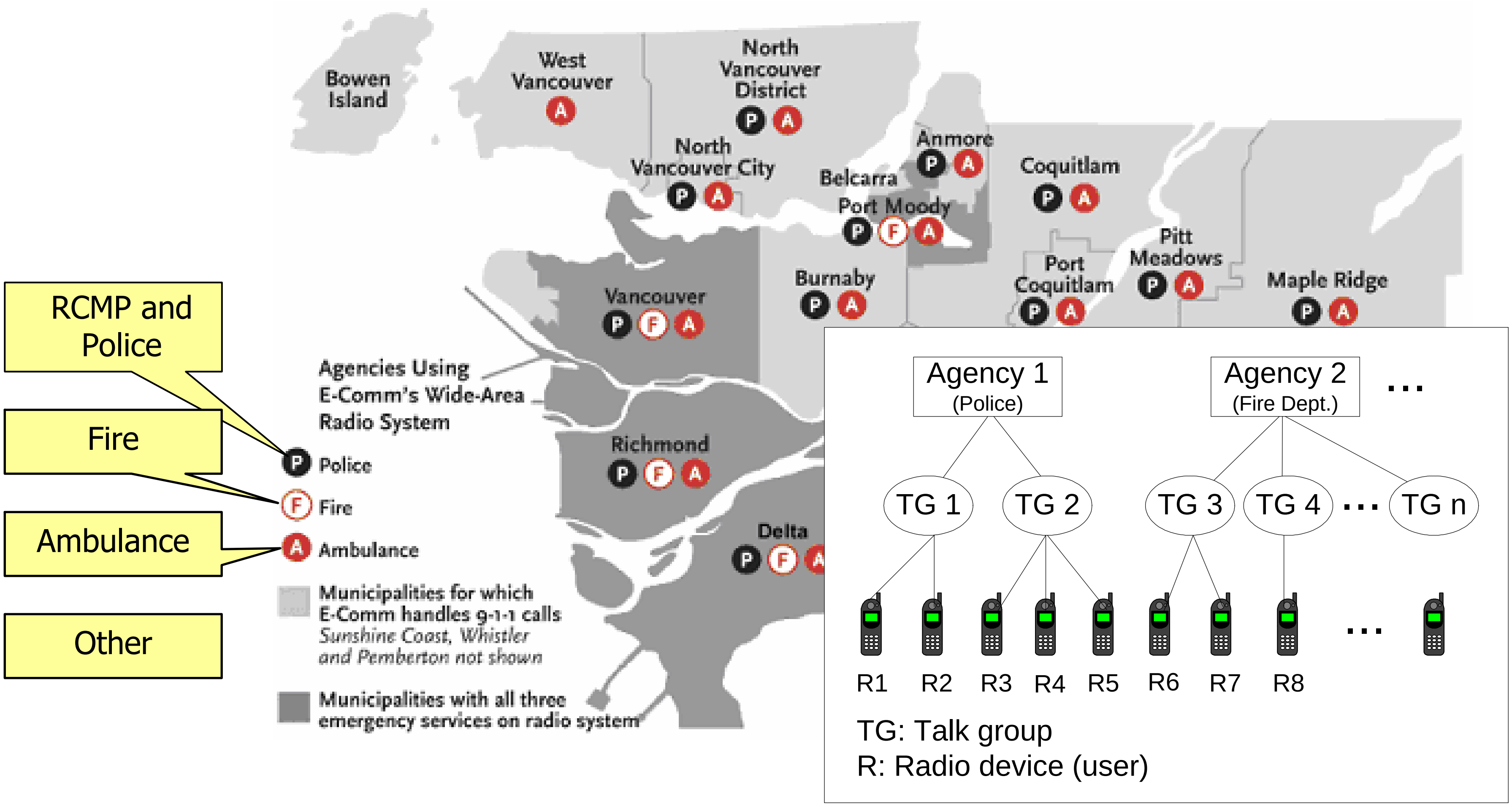
Road map

- Introduction and background
- Traffic data analysis
- Traffic modeling
- WarnSim: a simulator for public safety wireless networks (PSWN)
- Simulation and prediction
- Conclusions and future work

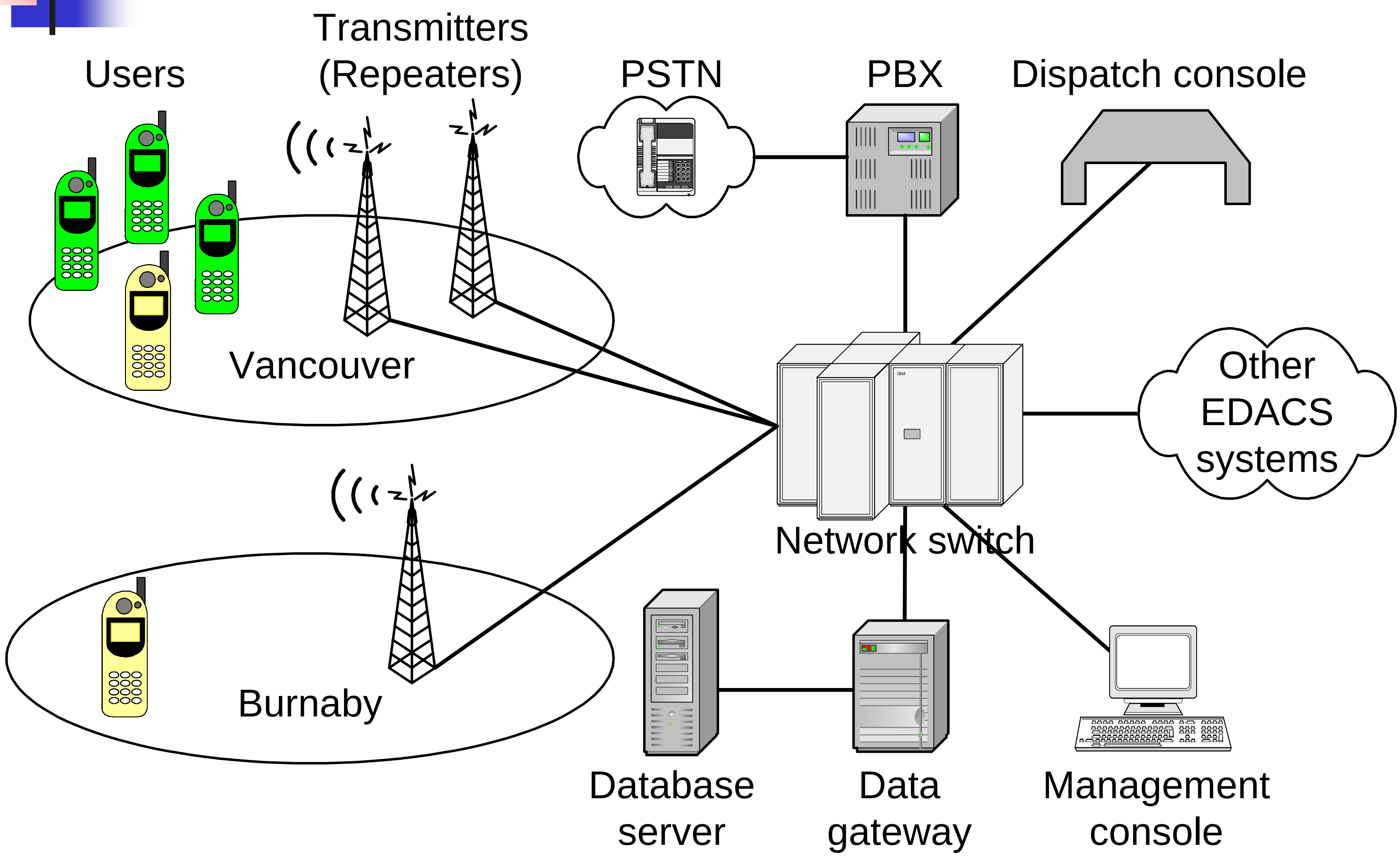
E-Comm

- Emergency Communications for Southwestern British Columbia Inc.
- Public safety wireless network (PSWN) service provider for Southwestern British Columbia
- $160 million project with $41 million annual operating budget
- Uses Enhanced Digital Access Communications System (EDACS) as its infrastructure network
- EDACS and similar systems are popular and are deployed by various emergency agencies worldwide

E-Comm network coverage and user agencies



E-Comm network architecture



Motivations and objectives

- Motivations:
  - call traffic data from PSWN are rare
  - deployment costs of new channels are very high
- Objectives:
  - develop statistical models of call traffic
  - evaluate performance of the E-Comm network:
    - call blocking probability and channel utilization
  - Predict future network performance

Road map

- Introduction and background
- Traffic data analysis
- Traffic modeling
- WarnSim: a simulator for PSWN
- Simulation and prediction
- Conclusions and future work

Traffic data description

- 2001 data set:
  - 2 days of traffic data
- 2002 data set:
  - 28 days of continuous traffic data
  - 2002-02-10 to 2002-03-09 (1,916,943 calls)
- 2003 data set:
  - 92 days of continuous traffic data
  - 2003-03-01 to 2003-05-31 (8,756,930 calls)

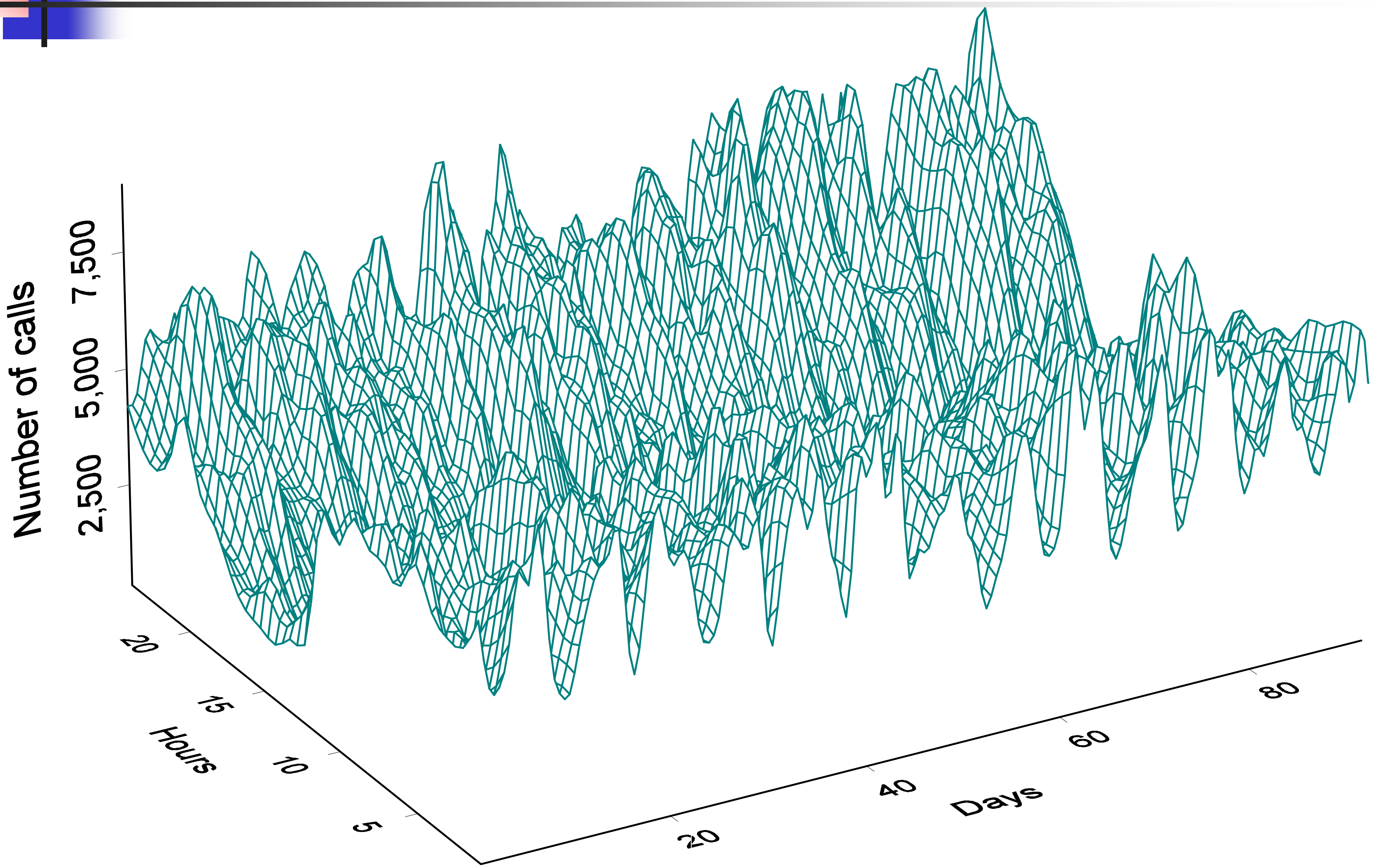
Traffic data sample

Call arrival time	Duration (ms)	Caller agency
2003-05-01 00:00:09.620	1990	5

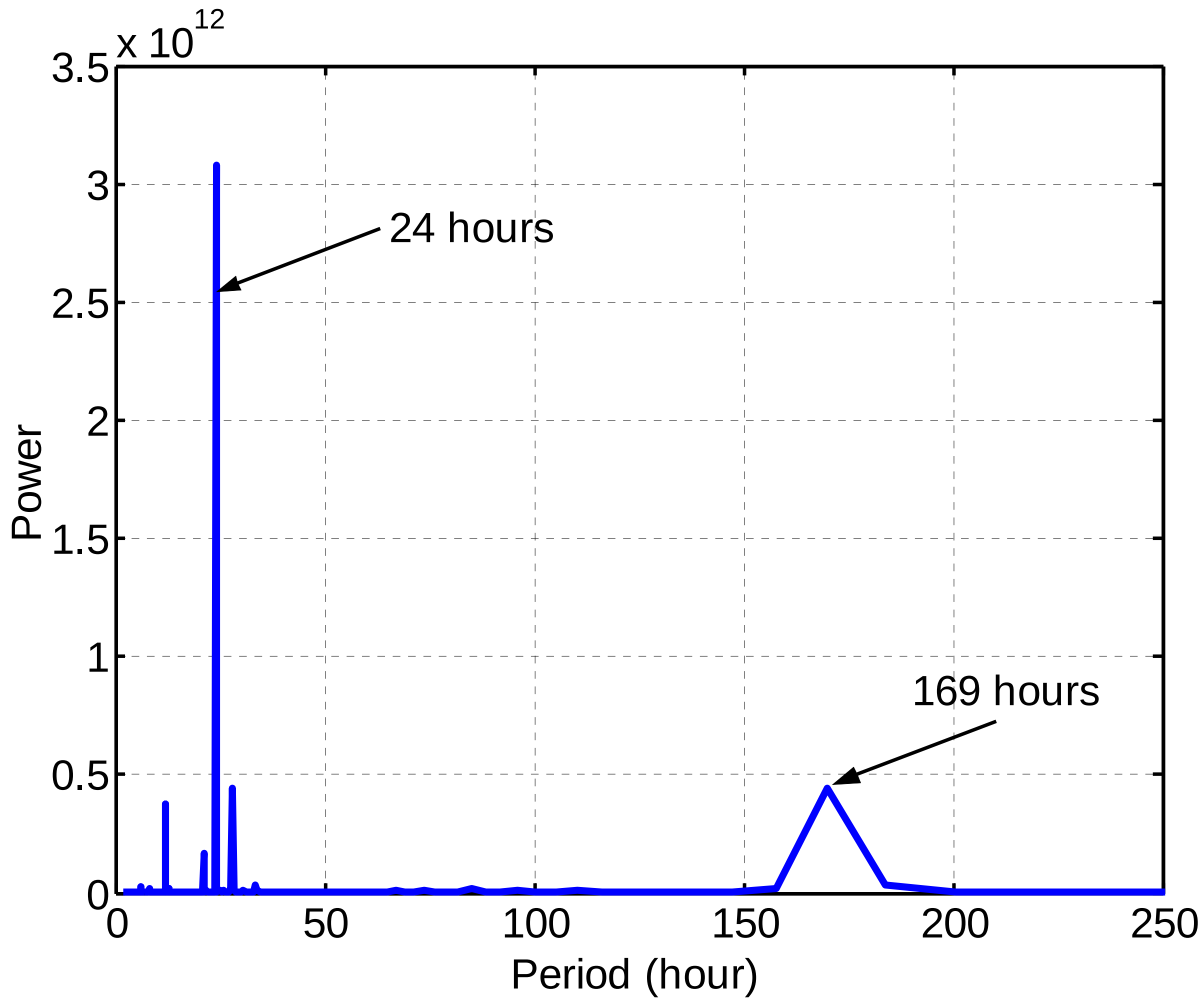
Caller	Callee	System ID	Channel no.
9999	1111	1, 7	3, 4

- Call made by caller 9999 to callee 1111
- Call made at 2003-05-01 00:00:09.620
- Call duration: 1,990 ms
- Covered Systems 1 and 7. Employed channel no. 3 in System 1 and channel no. 4 in System 7
- Caller belonged to Agency 5 (RCMP)

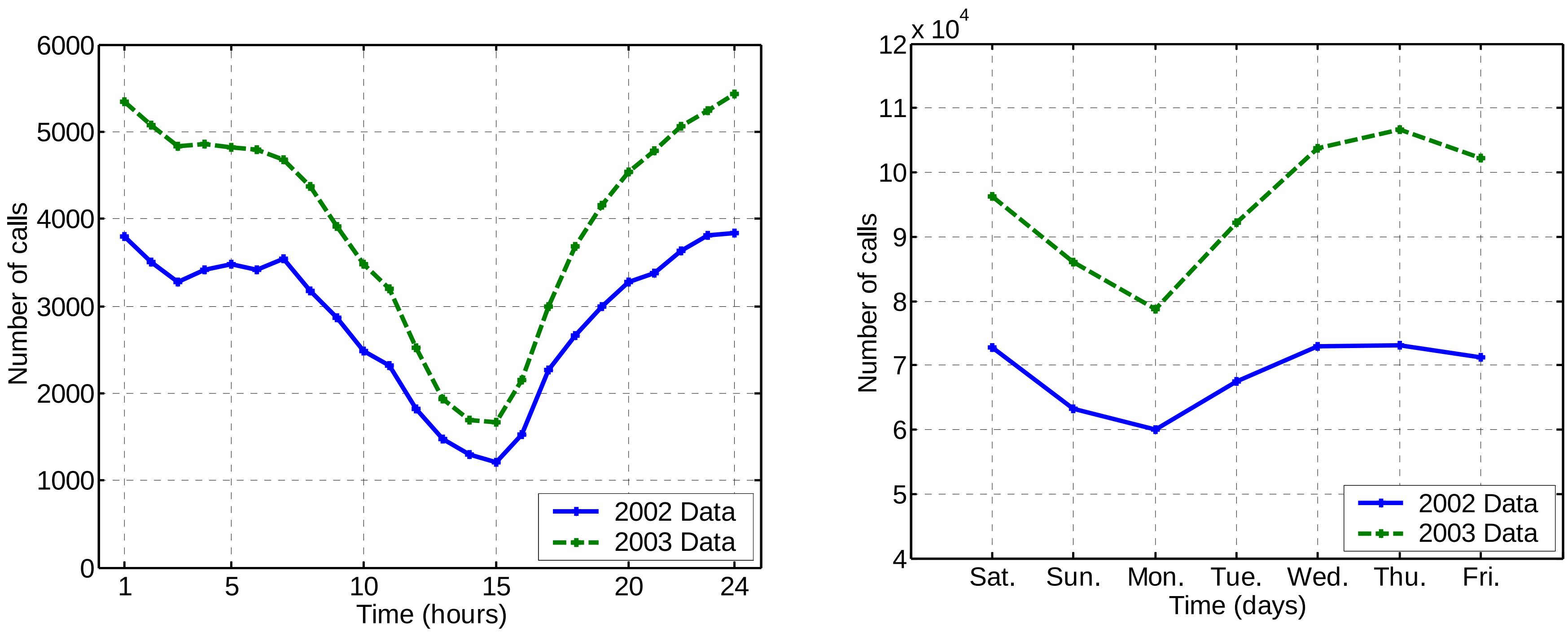
Hourly call arrival rate in 2003



Hourly call arrival rate in 2003: power spectrum

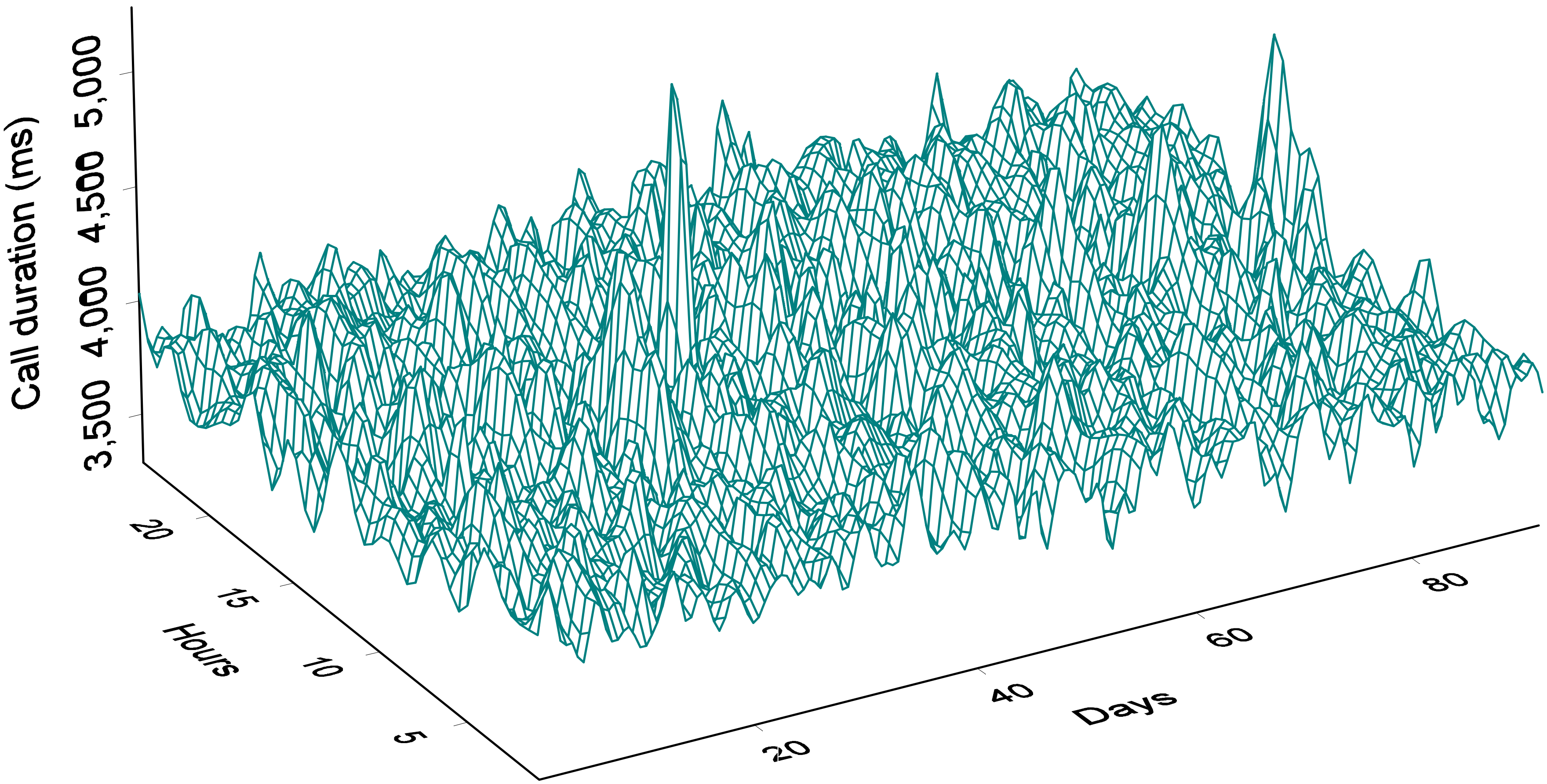


Call arrival rate in 2003: cyclic patterns

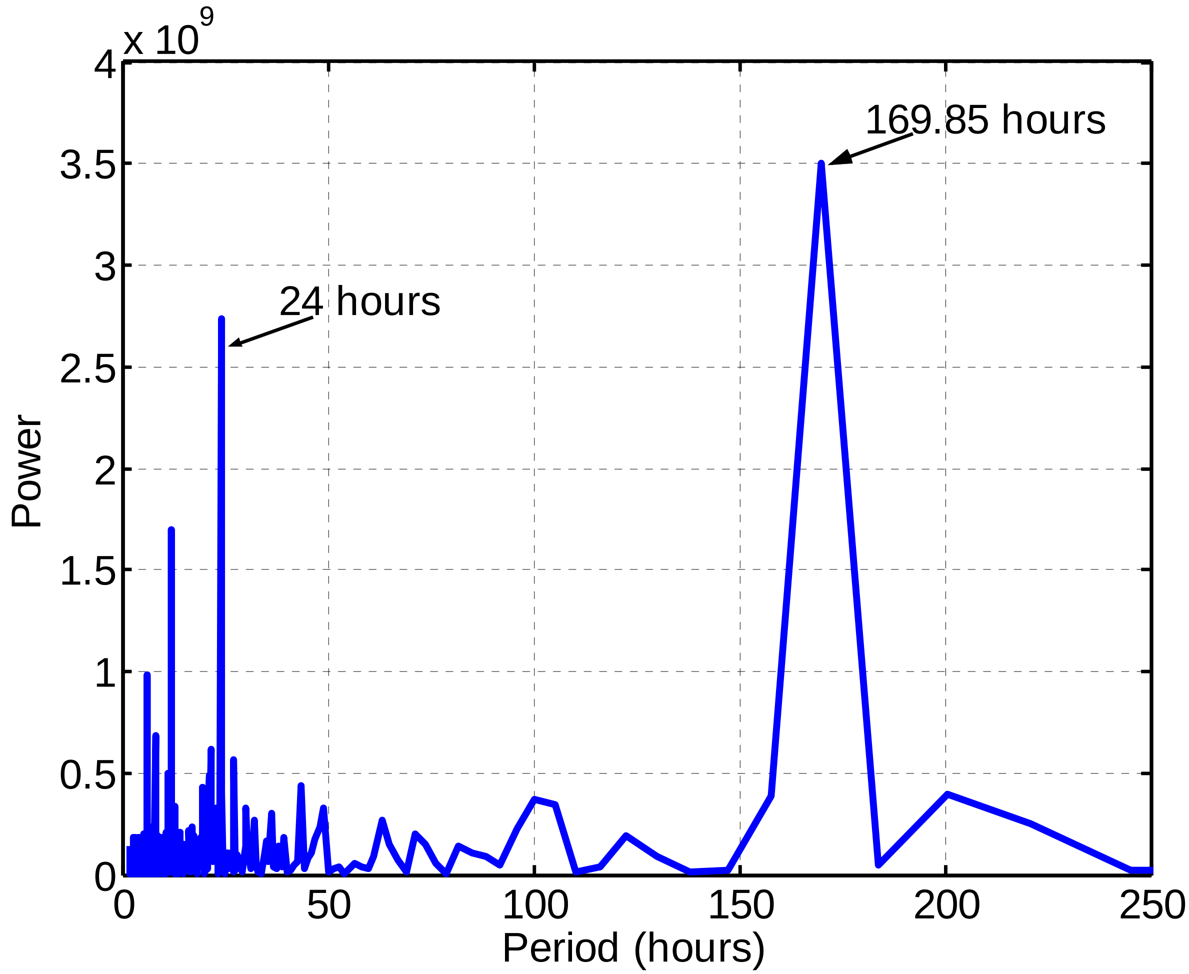


- The busiest hour is around midnight
- The busiest day is Thursday
- Useful for scheduling periodical maintenance tasks

Call duration in 2003: hourly average



Call duration in 2003: power spectrum



Agencies and daily call arrival rates

Agency ID	Average daily call arrival rate		Change
	Year 2002	Year 2003	
1	93	307	230%
2	27,803	27,659	-1%
3	1,191	1,266	6%
4	855	894	5%
5	25,994	48,915	88%
…	…	…	…
Total	68,462	95,184	39%

- Agencies have different network usage patterns:
  - two heavy user agencies account for most of the traffic
  - change in call arrival rates differ significantly among agencies

Road map

- Introduction and background
- Traffic data analysis
- Traffic modeling
- WarnSim: a simulator for PSWN
- Simulation and prediction
- Conclusions and future work

Failure of Erlang models in E-Comm

- Erlang B model assumes:
  - exponentially distributed call holding time
  - calls that cannot obtain free channels are rejected immediately
- Erlang C model assumes:
  - exponentially distributed call holding time
  - calls that cannot obtain free channels are put into a FIFO queue of infinite size
- These assumptions do not hold in the E-Comm network

Traffic modeling procedure

- Extract 500 sequential data samples (call holding time/call inter-arrival time) from traffic data table
- Select a candidate distribution (exponential, lognormal, or gamma) and use Maximum Likelihood Estimation to estimate its parameters
- Use Kolmogorov-Smirnov goodness-of-fit (GoF) test to evaluate the candidate distribution
  - test result p-value > 0.03: candidate distribution is likely to be accepted

Modeling call holding time of Agency 2

- Estimate distribution parameters and Kolmogorov-Smirnov GoF test results (p-value) for Agency 2 during the three busiest hours in 2002 dataset
- Results with p-value > 0.03 are marked in yellow
- Lognormal distribution is likely to be accepted

Distributions	Distribution parameters and K-S test results		
	Busy hour 1	Busy hour 2	Busy hour 3
Exponential	β = 3683.6 p-value = 0	β = 3664.06 p-value = 0	β = 3658.56 p-value = 0
Lognormal	σ = 8.0538 μ = 0.5505 p-value = 0.0832	σ = 8.0378 μ = 0.5769 p-value = 0.4952	σ = 7.9872 μ = 0.6334 p-value = 0.2634
Gamma	β = 1108.0657 k = 3.3246 p-value = 0.0002	β = 1173.6163 k = 3.1222 p-value = 0.0137	β = 1493.315 k = 2.4501 p-value = 0.0027

Modeling call holding time: results

Exponential	Agency 2	Agency 5	Others	All agencies
Busy hour 1	0.0000	0.0000	0.0000	0.0000
Busy hour 2	0.0000	0.0000	0.0000	0.0000
Busy hour 3	0.0000	0.0000	0.0000	0.0000

Gamma	Agency 2	Agency 5	Others	All agencies
Busy hour 1	0.0002	0.0000	0.0000	0.0011
Busy hour 2	0.0137	0.0012	0.0000	0.0006
Busy hour 3	0.0027	0.0001	0.0000	0.0422

Lognormal	Agency 2	Agency 5	Others	All agencies
Busy hour 1	0.0832	0.0258	0.0000	0.0629
Busy hour 2	0.4952	0.4522	0.0036	0.2689
Busy hour 3	0.2634	0.0474	0.0002	0.2160

Modeling call inter-arrival: results

Exponential	Agency 2	Agency 5	Others	All agencies
Busy hour 1	0.0019	0.0930	0.0000	0.3869
Busy hour 2	0.7604	0.9920	0.0000	0.9841
Busy hour 3	0.1232	0.5093	0.0000	0.4134

Gamma	Agency 2	Agency 5	Others	All agencies
Busy hour 1	0.4591	0.8678	0.0000	0.5797
Busy hour 2	0.6606	0.9990	0.3370	0.7903
Busy hour 3	0.7863	0.5090	0.0064	0.3931

Lognormal	Agency 2	Agency 5	Others	All agencies
Busy hour 1	0.0001	0.0017	0.0001	0.0004
Busy hour 2	0.0002	0.0103	0.0002	0.0078
Busy hour 3	0.0009	0.0007	0.0001	0.0009

Call coverage

- Calls in the E-Comm network are group calls and most of them cover more than one system
- Call coverage pattern (systems a call covers) is determined by the organization of talk groups and deployment of radio devices
- Assumption: call coverage pattern remains constant

Call coverage	Percentage
System ID: 1, 2, 3	1.35%
System ID: 1, 3, 8, 10, 11	2.07%
System ID: 3, 5, 7, 9, 10	7.08%
…	…

Mobility of radio devices/call handover

- Mobility of radio devices and call handover are major concerns for micro-cell cellular networks
- They are of little importance in the E-Comm network:
  - E-Comm network is a wide area radio network with each system covering a citywide area
  - average call duration is 3.8 seconds
  - negligible probability for a radio device to move between two systems during such a short time

Proposed call traffic model

- Use lognormal distribution to model call holding time at user agency level
- Use exponential distribution to model call inter-arrival time at user agency level
- Assume call coverage pattern remains constant

	Agency 2	Agency 5	Others
Call holding time	lognormal $\sigma = 8.05$ $\mu = 0.55$	lognormal $\sigma = 8.09$ $\mu = 0.73$	lognormal $\sigma = 7.88$ $\mu = 0.82$
Call inter-arrival time	exponential β_1	exponential β_2	exponential β_3

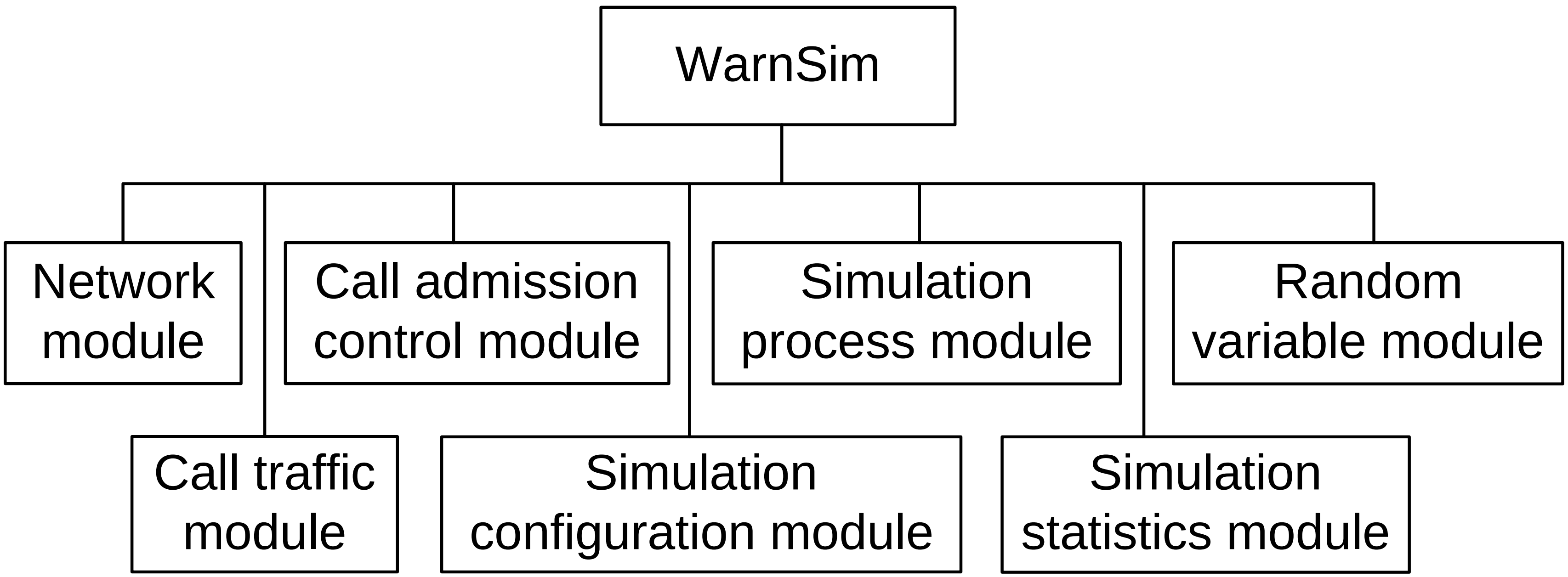
Road map

- Introduction and background
- Traffic data analysis
- Traffic modeling
- WarnSim: a simulator for PSWN
- Simulation and prediction
- Conclusions and future work

WarnSim overview

- Simulators such as OPNET and ns-2 are designed for packet-switched networks
- WarnSim is a simulator developed for circuit-switched networks, such as PSWN
- WarnSim:
  - publicly available simulator
  - effective, flexible, and easy to use
  - developed using Microsoft Visual C# .NET
  - operates on Windows platforms
  - contains more than 10,000 lines of code

WarnSim: module diagram



WarnSim modules (1)

- Network module:
  - models the PSWN cells (systems)
  - distributes calls to covered cells
  - tracks the number of free/occupied channels in each cell
  - periodically updates the channel status in each cell
- Call traffic module:
  - generates call traffic based on user-defined distributions
  - imports traffic trace from text files/databases for trace-driven simulations
  - combines traffic from multiple sources

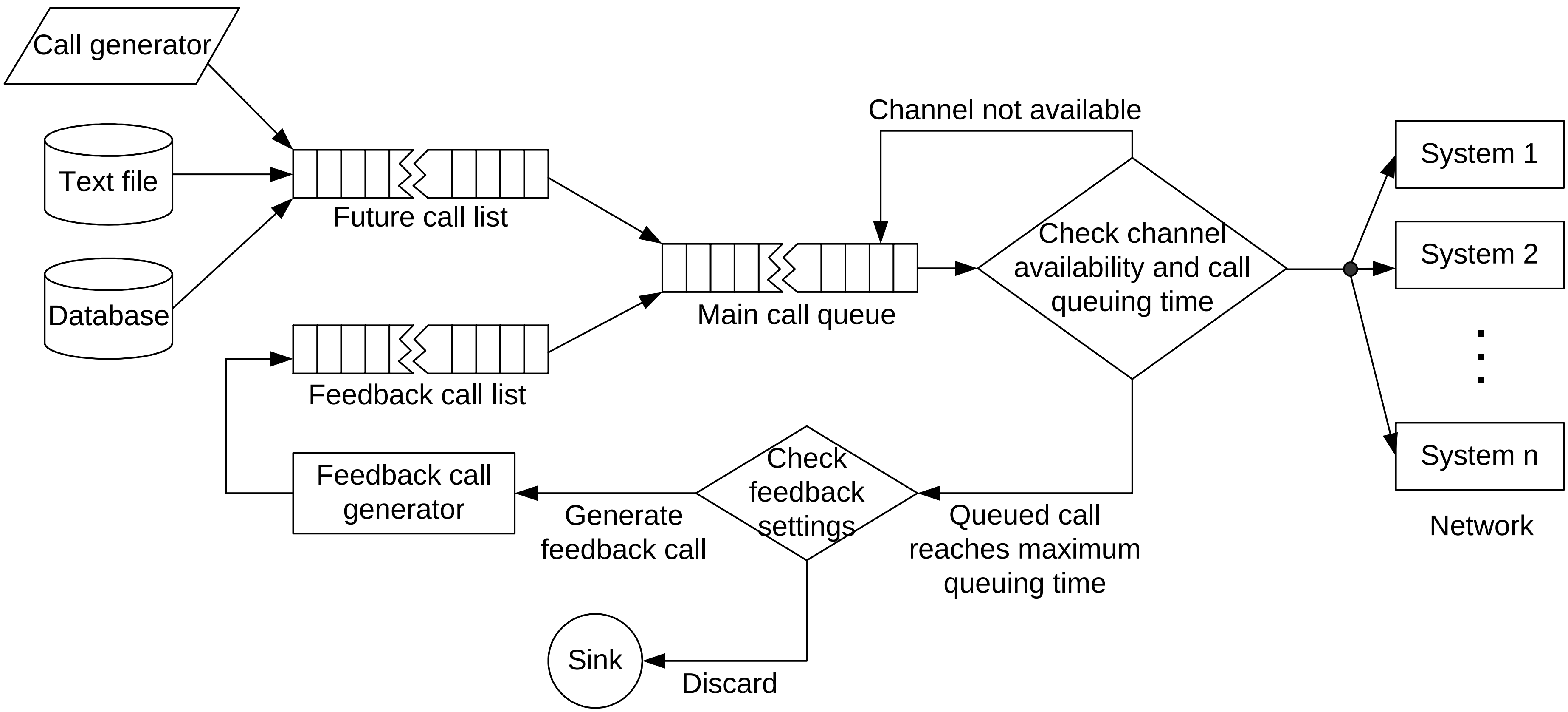
WarnSim modules (2)

- Call admission control module:
  - processes calls from the call traffic module
  - communicates with the network module to determine if there are available channels for a call to be established
  - manages the retrying mechanism of blocked calls
- Simulation configuration module:
  - keeps track of parameters such as call queuing mechanism and parameters such as maximum call queuing time, simulation duration, and simulation granularity

WarnSim modules (3)

- Simulation process module:
  - uses a timer to control and synchronize the operation of the WarnSim modules
- Simulation statistics module:
  - collects real-time and summary statistics of cells: number of calls, blocked calls, call blocking probability, and channel utilization
  - displays and visualizes simulation results
- Random variable module:
  - generates random variables: uniform, exponential, gamma, normal, lognormal, loglogistic, and Weibull

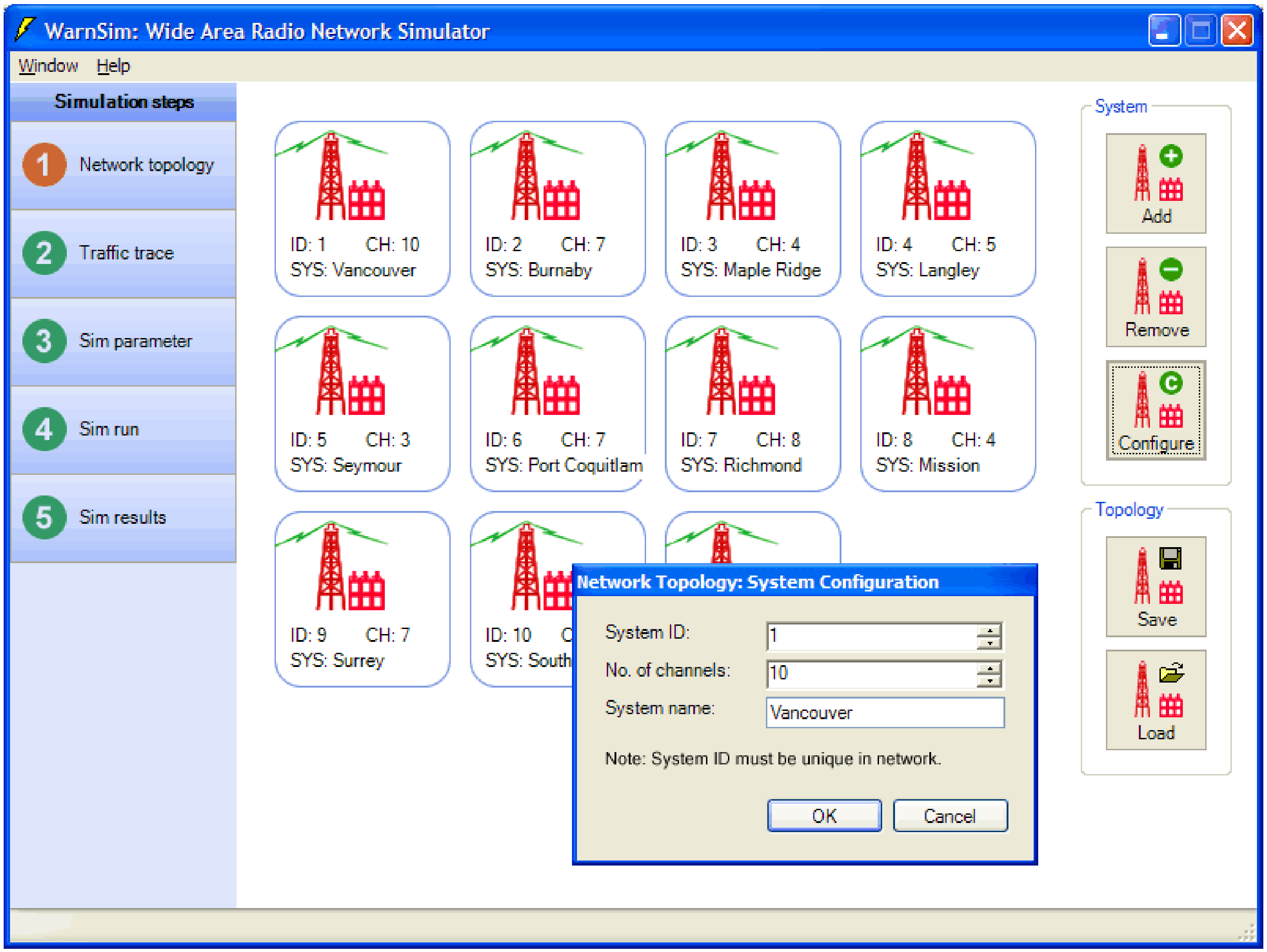
High level diagram of WarnSim



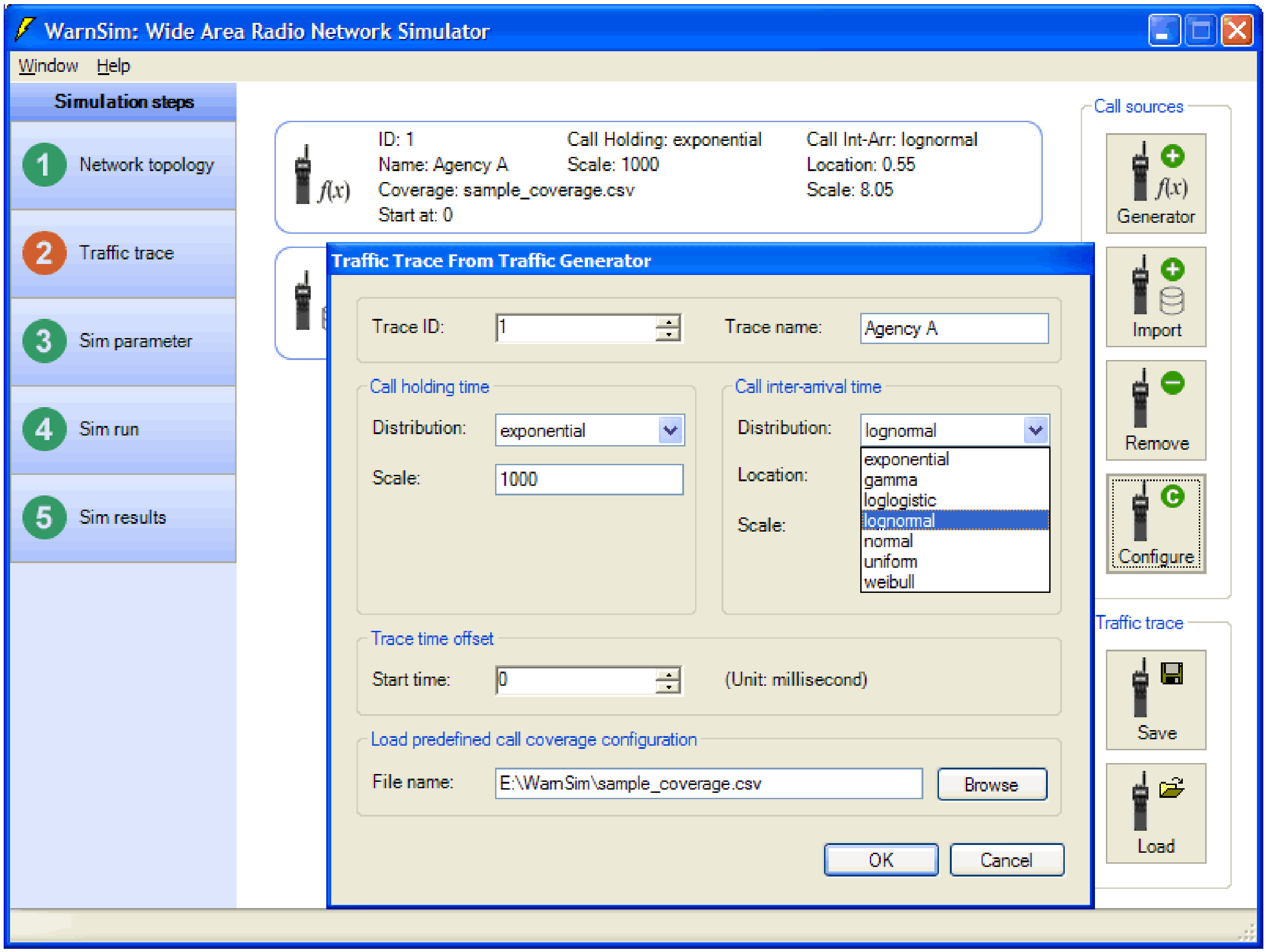
WarnSim simulation steps

- Setup network topology
- Setup traffic sources
- Configure simulation parameters
- Run the simulation
- Analyze simulation results

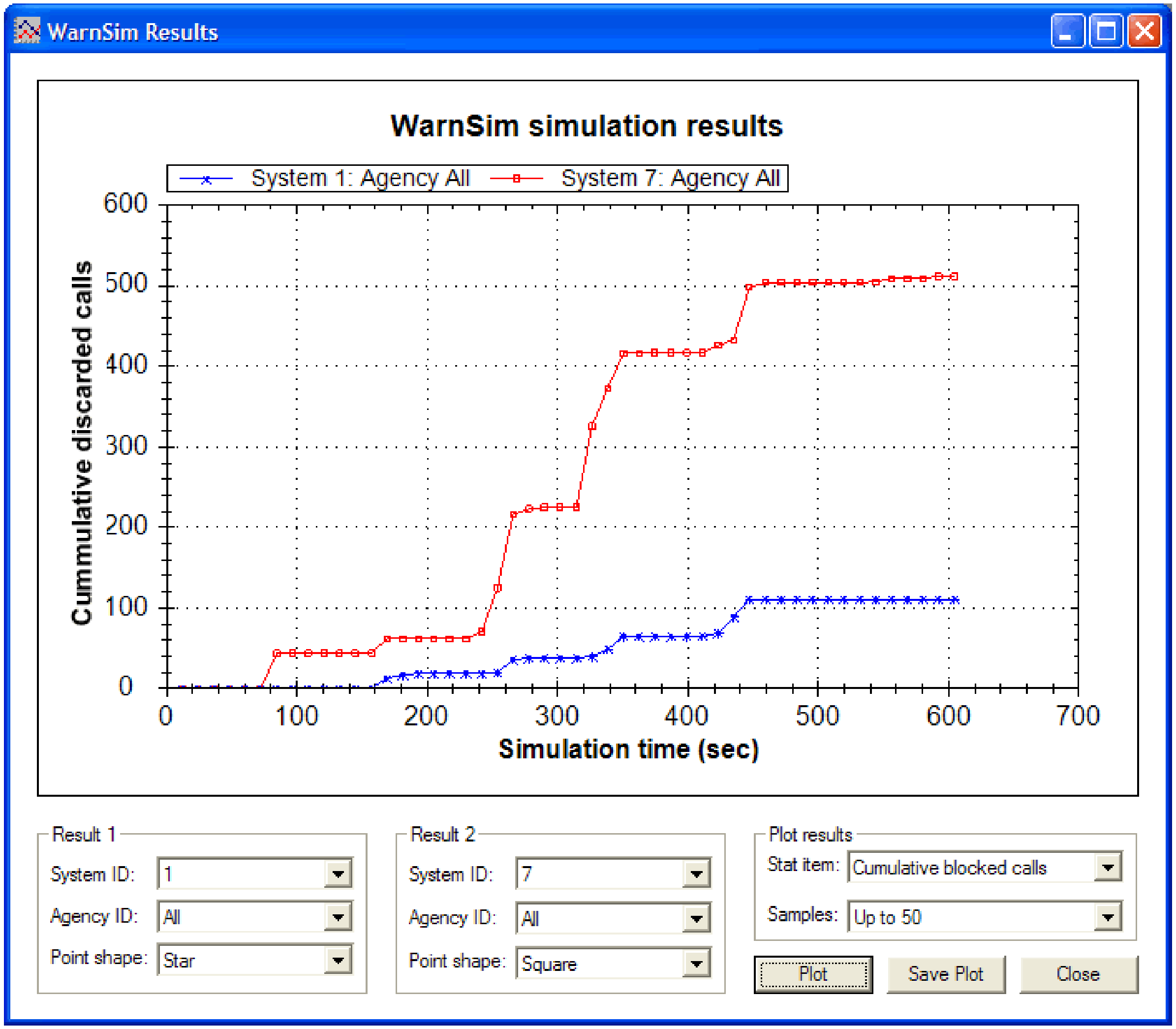
Network topology setup



Traffic trace generator



WarnSim results



Road map

- Introduction and background
- Traffic data analysis
- Traffic modeling
- WarnSim: a simulator for PSWN
- Simulation and prediction
- Conclusions and future work

WarnSim validation

	Erlang B model	WarnSim
Network configuration	10 phone lines	1 system with 10 channels
Call traffic volume	10 Erlangs	10 Erlangs
Call holding time	exponentially distributed	exponentially distributed with mean value of 180 seconds
Call inter-arrival time	exponentially distributed	exponentially distributed with mean value of 18 seconds
Dealing with blocked calls	blocked calls neither queued nor retried	*Max Queuing Time* = 0 blocked calls not retried
Call blocking probability	21.5%	17% – 27%, average = 21.86% (10 simulation runs)

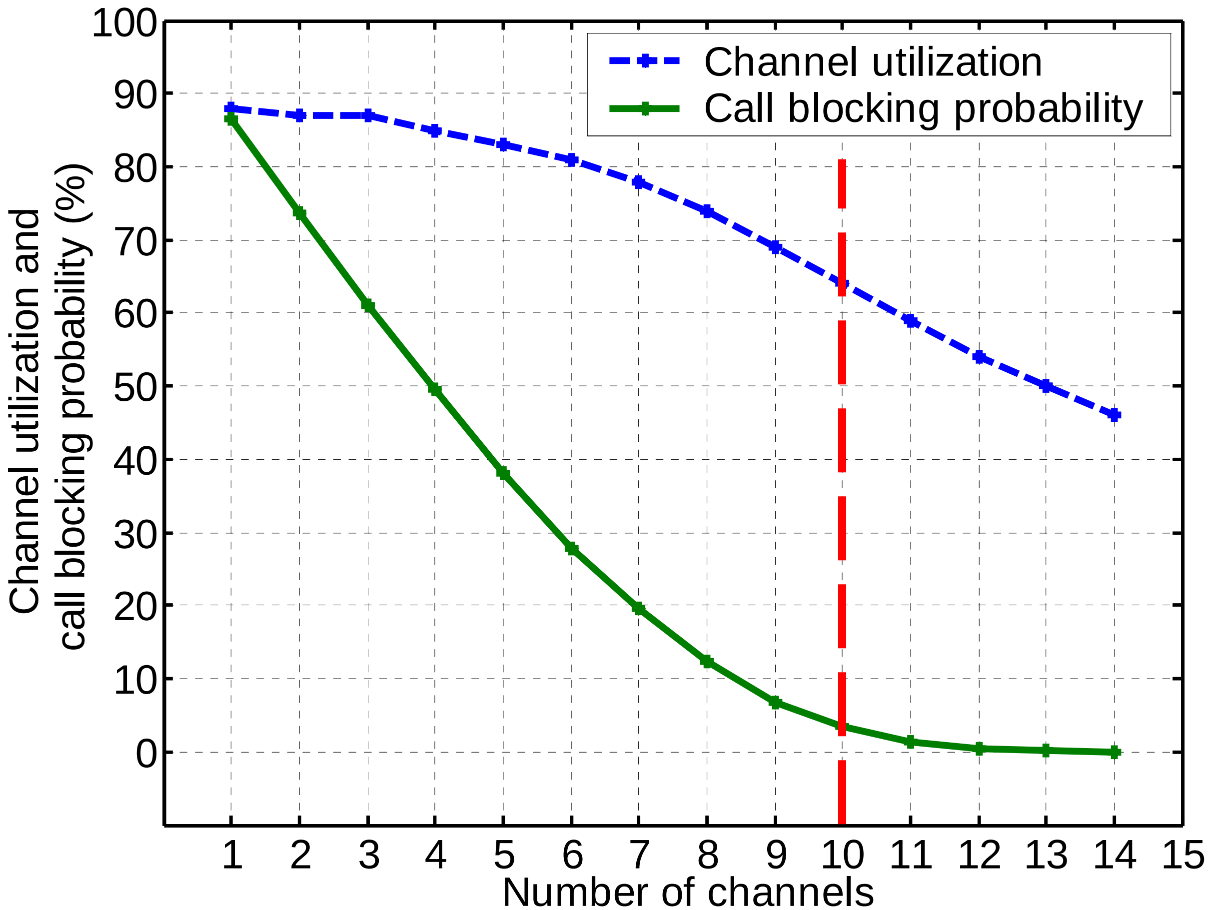
Channels and Grade of Service

- Busy hour (2003-05-15 2:00–3:00 am) traffic data
- Maximum queuing time is set to zero (calls that cannot obtain required channels are dropped immediately)
- Network configuration:

System ID	1	2	3	4	5	6	7	8	9	10	11
Channels	variable	7	4	5	3	7	8	4	7	6	3

- Vary the number of available channels in System 1 from 1 to 14

Channels and Grade of Service



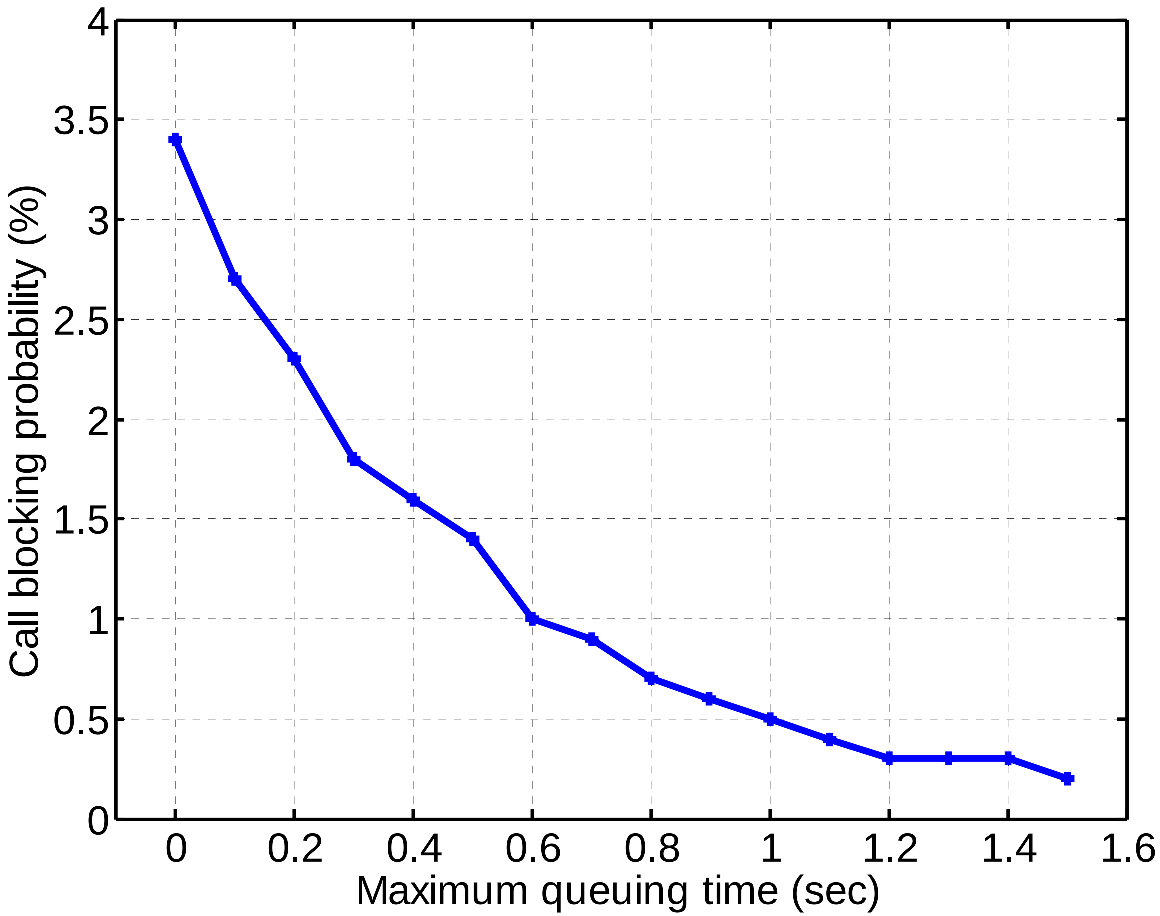
Queuing and Grade of Service

- Busy hour (2003-05-15 2:00–3:00 am) traffic data
- Network configuration:

System ID	1	2	3	4	5	6	7	8	9	10	11
Channels	10	7	4	5	3	7	8	4	7	6	3

- Increase maximum queuing time from 0 to 1.5 seconds

Queuing and Grade of Service



Traffic model validation

- Compare simulation results for busy hours:
  - collected traffic (3 busiest hours in 2003)
  - traffic generated by proposed model

	Agency 2	Agency 5	Others
Call holding time	lognormal $\sigma = 8.05$ $\mu = 0.55$	lognormal $\sigma = 8.09$ $\mu = 0.73$	lognormal $\sigma = 7.88$ $\mu = 0.82$
Call inter-arrival time	exponential $\beta = 1354$	exponential $\beta = 761$	exponential $\beta = 3480$

- Network configuration:

System ID	1	2	3	4	5	6	7	8	9	10	11
Channels	10	7	4	5	3	7	8	4	7	6	3

Traffic model validation results

System ID	Actual blocking probability (%)	Actual channel utilization (%)	Simulated blocking probability (%)	Simulated channel utilization (%)
1	1.9 – 3.5	57 – 65	2.9 – 3.9	53 – 56
2	0.0 – 0.6	29 – 48	0.8 – 1.1	34 – 37
3	0.0	11 – 14	0.0	11
4	0.0 – 0.4	21 – 23	0.4 – 1.3	21 – 26
5	0.0	4 – 17	0.0 – 1.1	10 – 11
6	0.0 – 0.3	19 – 42	0.1 – 0.3	27 – 29
7	0.0 – 0.4	25 – 34	0.0 – 0.2	25 – 27
8	0.0	8 – 11	0.0	9 – 10
9	0.3 – 0.5	37 – 43	1.1 – 2.0	36 – 39
10	0.0	16 – 26	0.1 – 0.2	20 – 22
11	0.0	6 – 10	0.0	6 – 8

Performance prediction

- Number of calls made by Agency 5 increases by 100% from the busiest hour in 2003:
  - maximum queuing time is set to zero
  - parameters for WarnSim call traffic generator

	Agency 2	Agency 5	Others
Call holding time	lognormal σ = 8.05 μ = 0.55	lognormal σ = 8.09 μ = 0.73	lognormal σ = 7.88 μ = 0.82
Call inter-arrival time	exponential β = 1354	exponential β = 381	exponential β = 3480

Performance prediction

System ID	Original blocking probability (%)	Original channel utilization (%)	Predicted blocking probability (%)	Predicted channel utilization (%)
1	1.9 – 3.5	57 – 65	12.1 – 12.6	71 – 72
2	0.0 – 0.6	29 – 48	5.1 – 7.0	54 – 55
3	0.0	11 – 14	0.1 – 0.4	16 – 17
4	0.0 – 0.4	21 – 23	1.5 – 3.7	35 – 39
5	0.0	4 – 17	1.0 – 1.3	16 – 18
6	0.0 – 0.3	19 – 42	2.1 – 2.7	44 – 45
7	0.0 – 0.4	25 – 34	0.6 – 0.8	38 – 40
8	0.0	8 – 11	0.0 – 0.3	16 – 18
9	0.3 – 0.5	37 – 43	9.0 – 10.1	60 – 62
10	0.0	16 – 26	1.3 – 1.5	35 – 38
11	0.0	6 – 10	0.3 – 0.9	11 – 13

Further simulations indicate:
Systems 1, 2, 4, and 9 require 4, 2, 1, and 3 additional channels, respectively, to ensure call blocking probability lower than 3%

Road map

- Introduction and background
- Traffic data analysis
- Traffic modeling
- WarnSim: a simulator for PSWN
- Simulation and prediction
- Conclusions and future work

Conclusions

- Described the E-Comm network structure and the E-Comm traffic data
- Analyzed call traffic data and showed its properties, such as cyclic patterns of call arrival rate
- Proposed statistical models for call traffic on user agency level
- Found for heavy user agencies:
  - call holding time follows lognormal distribution
  - call inter-arrival time follows exponential distribution

Conclusions

- Developed a new simulation tool, named WarnSim, for Public Safety Wireless Networks
- With WarnSim simulations:
  - validated the traffic models we proposed
  - evaluated the E-Comm network performance
  - predicted the future performance of the E-Comm network
- This modeling/simulation approach is efficient and effective

Future work

- Implement additional random variable generators in WarnSim to support more types of distributions
- Optimize WarnSim performance in terms of simulation speed
- Adopt traffic prediction model, such as cluster-based SARIMA (developed by L. Chen), to predict network performance

H. Chen and Lj. Trajković, "Trunked radio systems: traffic prediction based on user clusters," in *Proc. of International Symposium on Wireless Communication Systems 2004*, Sept. 2004, pp. 76-80.

References

[1] Emergency Communications for Southwest British Columbia Incorporated [Online]. Available: http://www.ecomm.bc.ca.

[2] ComNet Ericsson. *EDACS explained* [Online]. Available: http://www.trunkedradio.net/trunked/edacs/EDACS_Whitepaper.pdf.

[3] S. M. Ross, *Simulation*, 2nd ed. Toronto, ON: Academic Press, 1997, pp. 189–202.

[4] A. M. Law and W. D. Kelton, *Simulation Modeling and Analysis*, 3rd ed. Toronto, ON: McGraw-Hill, 2000, p. 4.

[5] W. Gilchrist, *Statistical Modelling*, Toronto, ON: John Wiley & Sons, 1984, pp. 194–205.

References: call holding time and call inter-arrival time

[6] V. A. Bolotin, "Telephone circuit holding time distributions," in *Proc. of 14th International Teletraffic Congress*, June 1994, pp. 125–134.

[7] F. Barceló and J. Jordán, "Channel holding time distribution in public telephony systems (PAMR and PCS)," *IEEE Trans. on Vehicular Technology*, vol. 49, no. 5, pp. 1615–1625, Sept. 2000.

[8] Y. Fang and I. Chlamtac, "Teletraffic analysis and mobility modeling of PCS networks," *IEEE Trans. on Communications*, vol. 47, no. 7, pp. 1062–1072, July 1999.

[9] V. Frost and B. Melamed, "Traffic modeling for telecommunications networks," *IEEE Communications Magazine*, vol. 32, no. 3, pp. 70–80, Mar. 1994.

[10] F. Barceló and J. I. Sȧnchez, "Probability distribution of the inter-arrival time to cellular telephony channels," in *Proc. of the 49th Vehicular Technology Conference*, May 1999, vol. 1, pp. 762–766.

[11] M. Rajaratnam and F. Takawira, "Handoff traffic characterization in cellular networks under nonclassical arrivals and service time distributions," *IEEE Trans. on Vehicular Technology*, vol. 50, no. 4, pp. 954–970, July 2001.

References: related work

[12] J. Song and Lj. Traković, "Modeling and performance analysis of public safety wireless networks," *First IEEE International Workshop on Radio Resource Management for Wireless Cellular*, to be presented.

[13] N. Cackov, J. Song, B. Vujičić, S. Vujičić, and Lj. Trajković, "Performance analysis of a public safety wireless network: a simulation approach," *Simulation: Transactions of The Society for Modeling and Simulation International*, submitted for publication.

[14] H. Chen and Lj. Trajković, "Trunked radio systems: traffic prediction based on user clusters," in *Proc. of International Symposium on Wireless Communication Systems 2004*, Sept. 2004, pp. 76-80.

[15] D. Sharp, N. Cackov, N. Lasković, Q. Shao, and Lj. Trajković, "Analysis of public safety traffic on trunked land mobile radio systems," *IEEE Journal on Selected Areas in Communications*, vol. 22, no. 7, pp. 1197–1205, Sept. 2004.

Thank you

- Thank D. Sharp from Planetworks and the management and technical staff at E-Comm for providing access to the activity data and for technical support
- Thank L. Chen, N. Cackov, and N. Lasković for suggestions in improving WarnSim
- Thank all of you for your precious time

Questions?