Call-level Multi-rate Loss Models for Elastic Traffic

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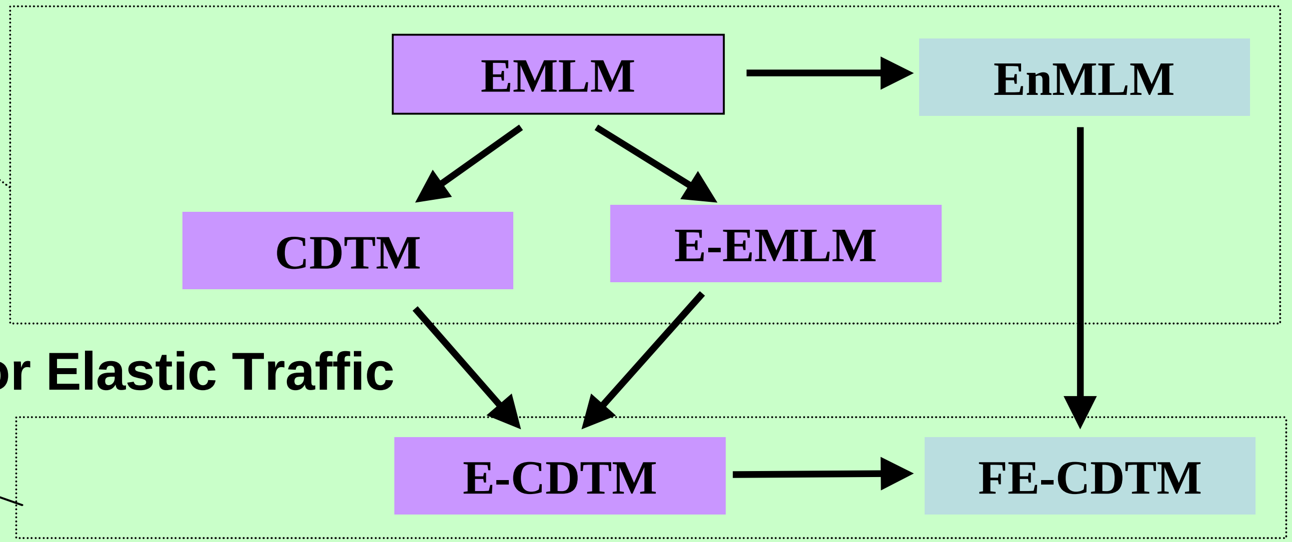
Outline

I. Introduction

II. Existing Models for Stream and Elastic Traffic

III. New Models for Elastic Traffic



IV. Evaluation – Numerical Examples

V. Conclusion

Introduction

End-to-End Link of Limited Capacity

- 1^{st} Service-class
- 2^{nd} Service-class
- K^{th} Service-class

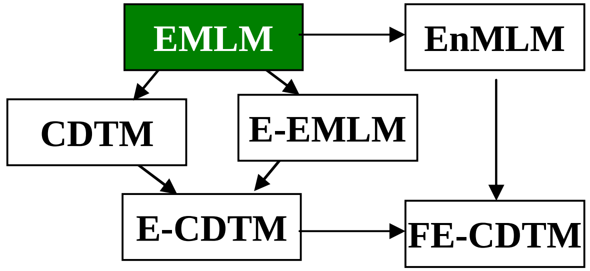
Arrival Process
- ***Random***
- ***Quasi-random***

Types of Traffic
- ***Stream*** (real-time video)
- ***Elastic*** (file transfer)

Performance Measures
- ***Call Blocking Probability***
- ***Link Utilization***

Review of the Existing Models

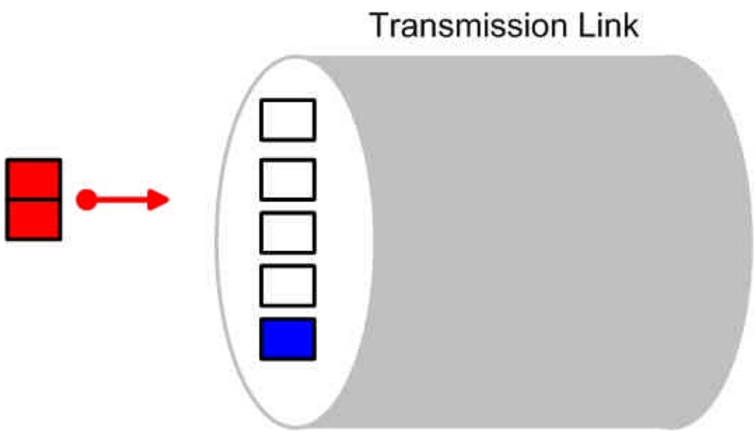
Erlang Multi-rate Loss Model (EMLM)



System parameters

- C : capacity
- K : service-classes

***Example*:**
Subscribers offering traffic to an ISDN node.



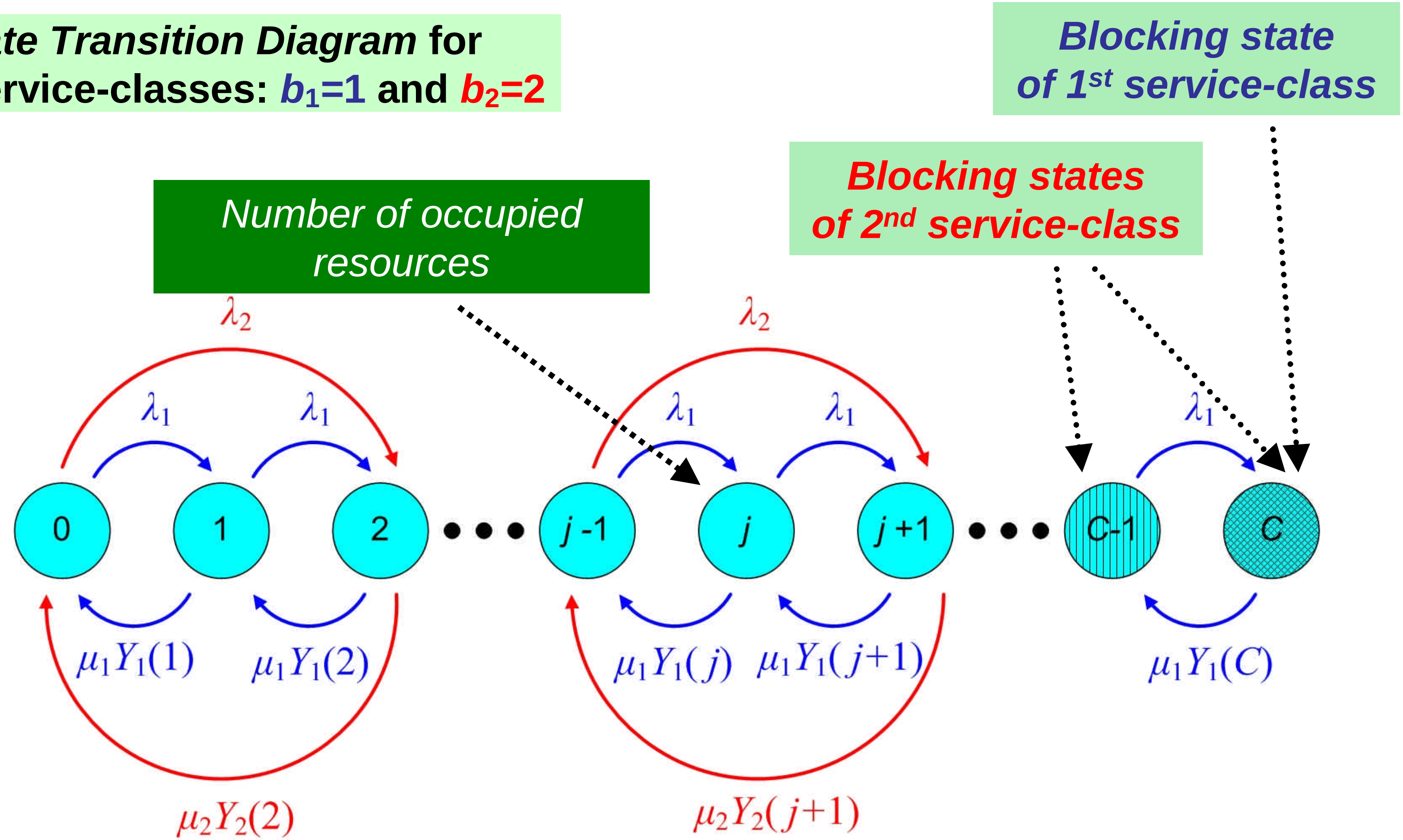
Service-class parameters

- μ_k : service rate
- μ_k^{-1} : mean service time (exponential)
- λ_k : arrival rate (Poisson process)
- **b_k : fixed bandwidth requirement**
- $\alpha_k = \lambda_k \mu_k^{-1}$: offered traffic-load

Review of the Existing Models

Erlang Multi-rate Loss Model (EMLM)

State Transition Diagram **for two service-classes: $b_1=1$ and $b_2=2$**



Review of the Existing Models

Erlang Multi-rate Loss Model (EMLM)

State Probability

$$\hat{q}(j) = \begin{cases} 1 & \text{for } j = 0 \\ \frac{1}{j} \sum_{k=1}^{K} \alpha_k b_k \hat{q}(j - b_k) & \text{for } j = 1,\ldots,C \\ 0 & \text{otherwise} \end{cases}$$

$$q(j) = \frac{\hat{q}(j)}{\sum_{j=0}^{C} \hat{q}(j)}$$

Call Blocking Probability

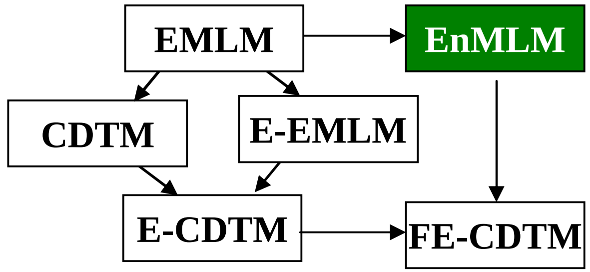
$$B_k = \sum_{j=C-b_k+1}^{C} q(j)$$

Link Utilization

$$U = \sum_{j=1}^{C} j\, q(j)$$

Review of the Existing Models

Engset Multi-rate Loss Model (EnMLM)

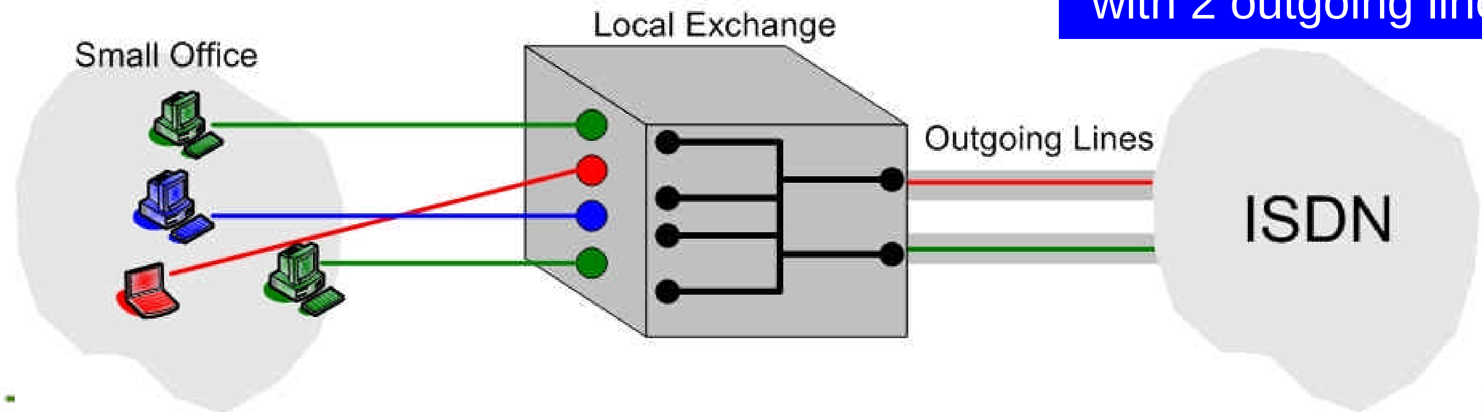


Service-class parameters

- **N_k : sources**
- n_k : number of in-service calls
- μ_k : service rate, μ_k^{-1} : mean service time (exponential)
- **v_k : arrival rate from an idle source**
- **$\lambda_k = v_k * (N_k - n_k)$**
- b_k : fixed bandwidth requirement
- $\alpha_k = v_k \mu_k^{-1}$: offered traffic-load from an idle source

Calls come from finite number of sources

Example:
4 users in an office with 2 outgoing lines



Review of the Existing Models

Engset Multi-rate Loss Model (EnMLM)

State Probability

$$\hat{q}(j) = \begin{cases} 1 & \text{for } j = 0 \\ \frac{1}{j} \sum_{k=1}^{K} (N_k - n_k + 1)\alpha_k b_k \hat{q}(j - b_k) & \text{for } j = 1, \ldots, C \\ 0 & \text{otherwise} \end{cases}$$

$$q(j) = \frac{\hat{q}(j)}{\sum_{j=0}^{C} \hat{q}(j)}$$

Call Blocking Probability

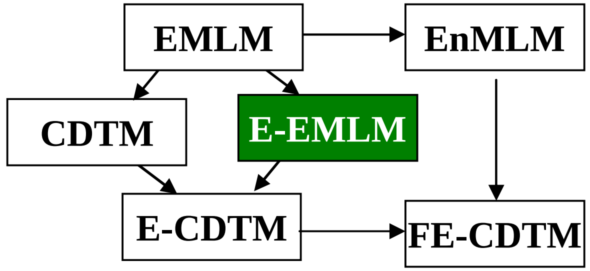
$$B_k = \sum_{j=C-b_k+1}^{C} q(j)$$

Link Utilization

$$U = \sum_{j=1}^{C} j\,q(j)$$

Review of the Existing Models

Extended Erlang Multi-rate Loss Model (E-EMLM)



System parameters

- **C : capacity**
- **T : virtual capacity ($T \geq C$)**
- K : service-classes
- **j : system state ($0 \leq j \leq T$)**
- **s : system allocation ($0 \leq s \leq C$)**

Used for Resource Allocation

Used for Call Admission Control

Service-class parameters

- **μ_k : ideal service rate,**
- **μ_k^{-1} : mean ideal service time (exponential)**
- λ_k : arrival rate (Poisson process)
- **b_k : peak bandwidth requirement**
- $\alpha_k = \lambda_k \mu_k^{-1}$: offered traffic-load

***Example*:**
A video call, while in-service, reduces its bandwidth.

Review of the Existing Models

Extended Erlang Multi-rate Loss Model (E-EMLM)

State Probability

$$\hat{q}(j)=\begin{cases}1 & \text{for } j=0\\ \frac{1}{\min(C,j)}\sum_{k=1}^{K}\alpha_k b_k \hat{q}(j-b_k) & \text{for } j=1,\ldots,T\\ 0 & \text{otherwise}\end{cases}$$

$$q(j)=\frac{\hat{q}(j)}{\sum_{j=0}^{T}\hat{q}(j)}$$

Call Blocking Probability

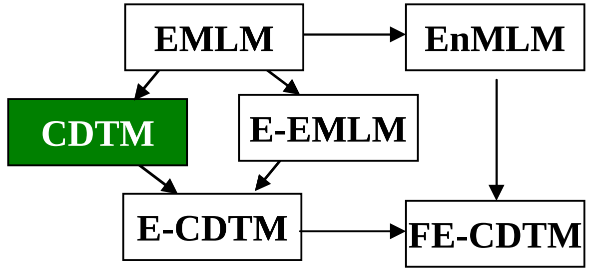
$$B_k=\sum_{j=T-b_k+1}^{T} q(j)$$

Link Utilization

$$U=\sum_{j=1}^{C} j\,q(j)+\sum_{j=C+1}^{T} C\,q(j)$$

Review of the Existing Models

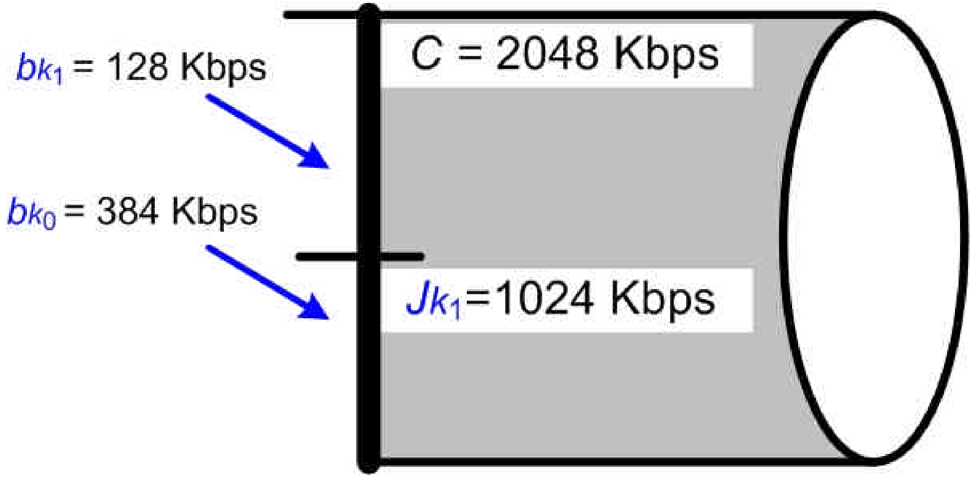
Connection-Dependent Threshold Model (CDTM)



Service-class parameters

- λ_k : arrival rate (Poisson process)
- **J_{k1}, J_{k2} , J_{k3},…, J_{ks_k} : thresholds**
- **b_{k0}, b_{k1}, b_{k2} , …, b_{ks_k} : bandwidth requirements**
- **μ_{k0}^{-1}, μ_{k1}^{-1},…, $\mu_{ks_k}^{-1}$ mean service time requirements**
- $\alpha_{kl} = \lambda_k \mu_{kl}^{-1}$: offered traffic-load

Indicate the occupied link bandwidth



***Example*:**
An arriving video call to an ISDN node requests for 384Kbps or, if the node is congested, 128 Kbps.
After accepted the bandwidth of the call is not altered.

Review of the Existing Models

Connection-Dependent Threshold Model (CDTM)

Assumptions

The recurrent calculation in CDTM is based on:

- ***local balance*** **between adjacent system-states.**
- ***migration approximation*****: calls accepted in the system with other than the maximum bandwidth requirement are negligible within a space, called migration space and related to the variable** $\delta_{k_0}(j)$**.**
- ***upward approximation:*** **calls accepted in the system with their maximum bandwidth are negligible within a space, called *upward space* and related to the variable** $\delta_{k_l}(j)$ **for** $l \neq 0$**.**

$$\delta_{k_0}(j) = \begin{cases} 1 & \text{when } 1 \le j \le C \text{ and } b_{k_l} = 0 \ (l \neq 0) \\ 1 & \text{when } j \le J_{k_0} + b_k \text{ and } b_{k_l} > 0 \ (l \neq 0) \\ 0 & \text{otherwise} \end{cases}$$

$$\delta_{k_l}(j) = \begin{cases} 1 & \text{when } J_{k_l} + b_{k_l} \ge j > J_{k_{l-1}} + b_{k_l} \text{ and } b_{k_l} > 0 \\ 0 & \text{otherwise} \end{cases} \quad \text{for } l \neq 0$$

Review of the Existing Models

Connection-Dependent Threshold Model (CDTM)

State Probability

$$\hat{q}(j) = \begin{cases} 1 & \text{for } j = 0 \\ \dfrac{1}{j} \sum_{k=1}^{K} \sum_{l=0}^{S_k} \alpha_{k_l} b_{k_l} \delta_{k_l}(j)\, \hat{q}(j - b_{k_l}) & \text{for } j = 1, \ldots, C \\ 0 & \text{otherwise} \end{cases}$$

$$q(j) = \frac{\hat{q}(j)}{\sum_{j=0}^{C} \hat{q}(j)}$$

Call Blocking Probability

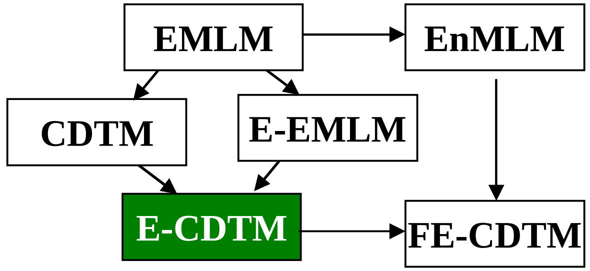
$$B_k = \sum_{j=C-b_{k_{S_k}}+1}^{C} q(j)$$

Link Utilization

$$U = \sum_{j=1}^{C} j\, q(j)$$

New Models

Extended Connection-Dependent Threshold Model (E-CDTM)



System parameters

- C : capacity
- **T : virtual capacity ($T \geq C$)**
- **$J_{k1}, J_{k2}, J_{k3}, \dots, J_{ks_k}$: thresholds**
- K : service-classes
- j : system state ($0 \leq j \leq T$)
- s : system allocation ($0 \leq s \leq C$)

Used for Call Admission Control

Indicate the occupied link bandwidth

***Example*:**
An arriving video call to an ingress MPLS node requests for 2048 or, if the node is congested, 1024 Kbps. After accepted the call can reduce its bandwidth to some extent.

New Models

Extended Connection-Dependent Threshold Model (E-CDTM)

State Probability

$$\hat{q}(j) = \begin{cases} 1 & \text{for } j = 0 \\ \dfrac{1}{\min(C,j)} \displaystyle\sum_{k=1}^{K} \sum_{l=0}^{S_k} \alpha_{k_l} b_{k_l} \delta_{k_l}(j)\, \hat{q}(j - b_{k_l}) & \text{for } j = 1,\ldots,T \\ 0 & \text{otherwise} \end{cases}$$

$$q(j) = \frac{\hat{q}(j)}{\sum_{j=0}^{T} \hat{q}(j)}$$

Call Blocking Probability

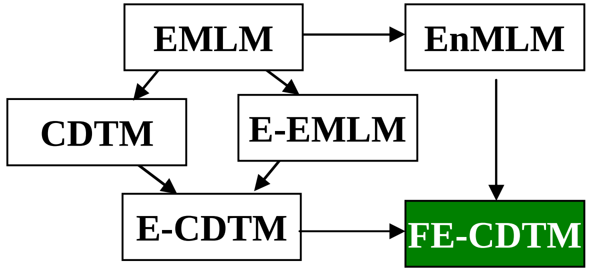
$$B_k = \sum_{j=T-b_{k_{S_k}}+1}^{T} q(j)$$

Link Utilization

$$U = \sum_{j=1}^{C} j\, q(j) + \sum_{j=C+1}^{T} C\, q(j)$$

New Models

Finite Extended Connection-Dependent Threshold Model (FE-CDTM)



System parameters

- C : capacity
- K : service-classes
- j : system state ($0 \le j \le T$)
- T : maximum system occupancy ($T \ge C$)
- s : system allocation ($0 \le s \le C$)

***Example*:**
In cellular 3G systems where in small cells we have to consider finite population is a potential application of FE-CDTM

Service-class parameters

- **N_k : sources** → *Calls come from finite number of sources*
- v_{kl} : arrival rate from an idle source
- $J_{k1}, J_{k2}, \ldots, J_{ks_k}$: thresholds
- $b_{k0}, b_{k1}, b_{k2}, \ldots, b_{ks_k}$: contingency bandwidth requirements
- $\mu_{k0}^{-1}, \mu_{k1}^{-1}, \mu_{k2}^{-1}, \ldots, \mu_{ks_k}^{-1}$ mean service time requirements
- $\alpha_{kl} = \lambda_k \mu_{kl}^{-1}$: offered traffic-load from an idle source

New Models

Finite Extended Connection-Dependent Threshold Model (FE-CDTM)

State Probability

$$\hat{q}(j) = \begin{cases} 1 & \text{for } j = 0 \\ \dfrac{1}{\min(C, j)} \displaystyle\sum_{k=1}^{K} \sum_{l=0}^{S_k} (N_k - \sum_{l=0}^{S_k} n_{k_l} + 1)\, \alpha_{k_l}\, b_{k_l}\, \delta_{k_l}(j)\, \hat{q}(j - b_{k_l}) & \text{for } j = 1, \ldots, T \\ 0 & \text{otherwise} \end{cases}$$

$$q(j) = \frac{\hat{q}(j)}{\sum_{j=0}^{T} \hat{q}(j)}$$

Call Blocking Probability

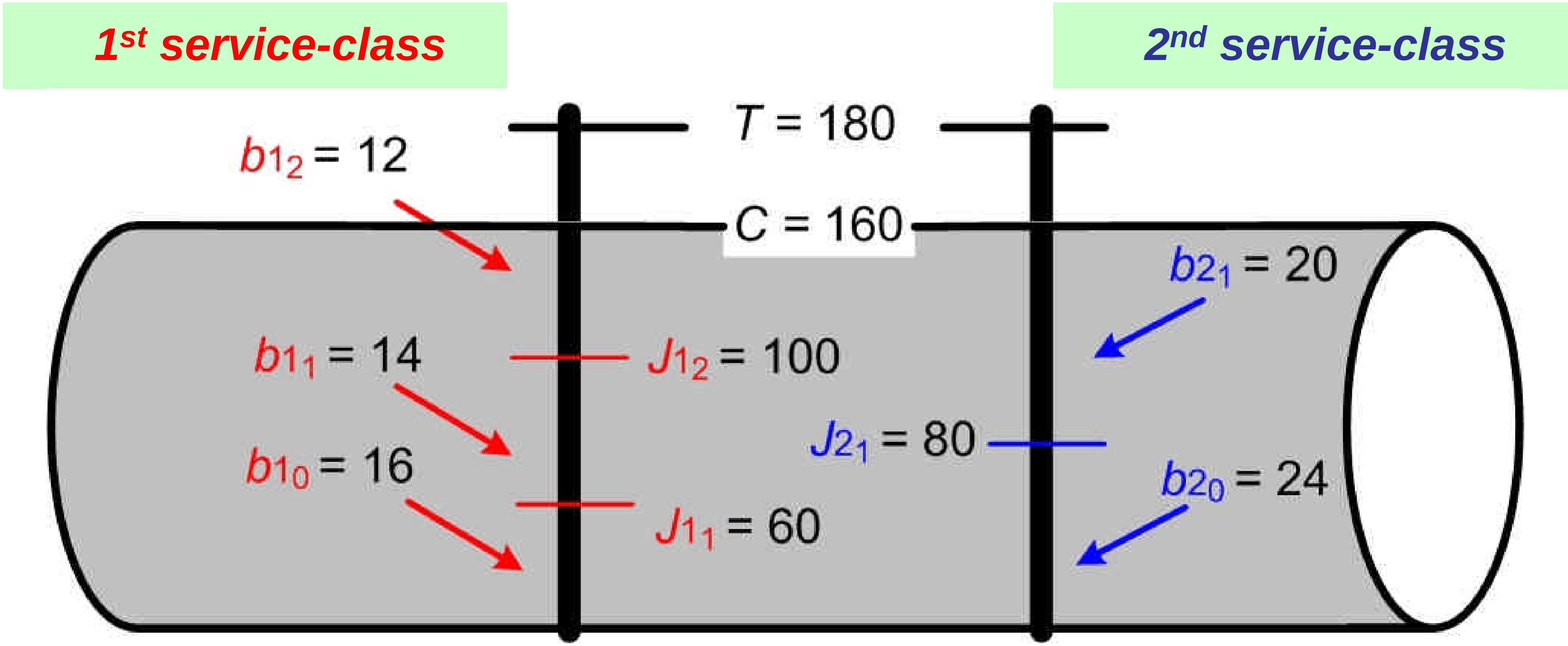
$$B_k = \sum_{j = T - b_{k_{S_k}} + 1}^{T} q(j)$$

Link Utilization

$$U = \sum_{j=1}^{C} j\, q(j) + \sum_{j=C+1}^{T} C\, q(j)$$

Evaluation – Numerical Examples

We compare *Analytical* vs *Simulation* results for both *E-CDTM* and *FE-CDTM*.



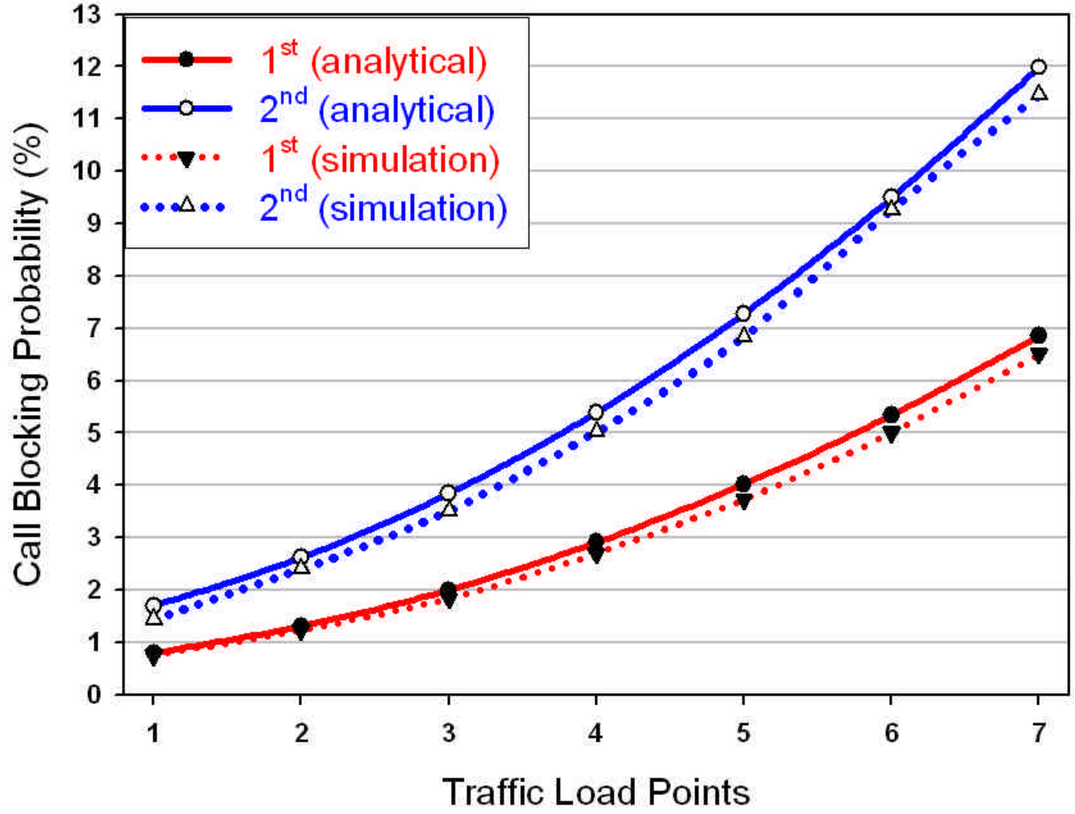
For example 1b.u. = 64 Kbps

Evaluation – Numerical Examples

Random Arrival Process
E-CDTM

Traffic-load Point	Traffic-load (a_1, a_2) erl
1	(2.0, 2.0)
2	(2.5, 2.0)
3	(3.0, 2.0)
4	(3.5, 2.0)
5	(4.0, 2.0)
6	(4.5, 2.0)
7	(5.0, 2.0)

Call Blocking Probability vs Traffic-load



Evaluation – Numerical Examples

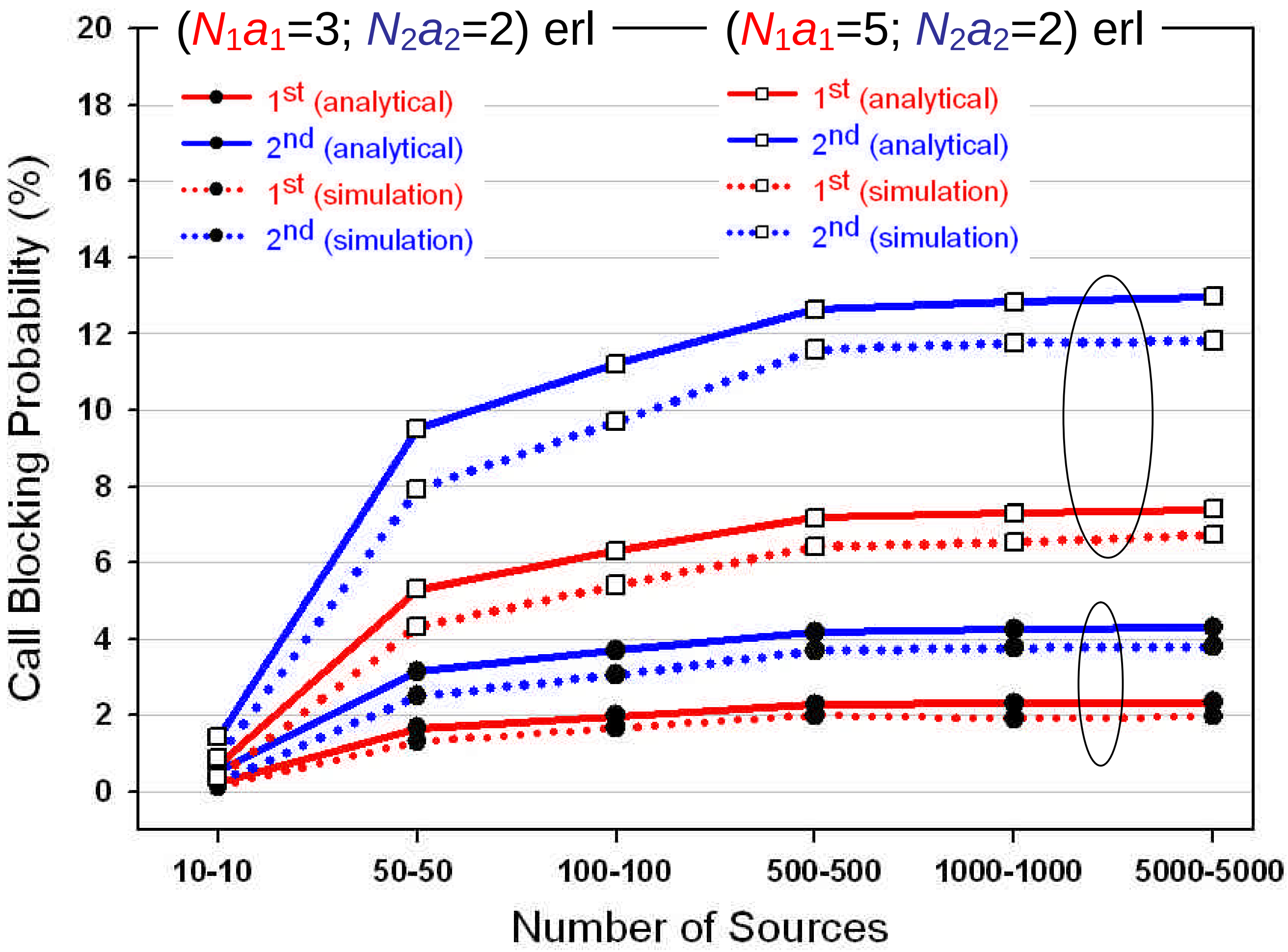
Random Arrival Process
E-CDTM

Link Utilization vs Traffic-load

Traffic-load Point	Traffic-load (a_1, a_2) erl	analytical	simulation
1	(2.0, 2.0)	78.82	79.12
2	(2.5, 2.0)	86.06	86.63
3	(3.0, 2.0)	92.98	93.39
4	(3.5, 2.0)	99.51	100.08
5	(4.0, 2.0)	105.59	106.37
6	(4.5, 2.0)	111.19	111.71
7	(5.0, 2.0)	116.29	117.11

Evaluation – Numerical Examples

Quasi-random Arrival Process
FE-CDTM



Conclusion

- **We review existing models for *stream* and *elastic* traffic**

- **We present two new models the *E-CDTM* and *FE-CDTM* for the analysis of *elastic* traffic in the case of *random* and *quasi-random* call arrivals**

- **We present recurrent formulas for the calculation of state probabilities and determine the *Call Blocking Probability* and *Link Utilization***

- **We validate by simulations the accuracy of the proposed calculation methods**

Thank You !