Teletraffic Advances in LEO Mobile Satellite Systems

TUTORIAL

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10th Int. Conf. Advances in Satellite and Space Commun. (SPACOMM)
Athens, Greece, April 22-26, 2018

Outline (1)

- Definitions
- The LEO – Mobile Satellite System (MSS) model
- The analytical model for Poisson traffic
- A recursive formula for the LEO-MSS (Complete Sharing (CS) policy – Poisson traffic)
- Performance measures (CS policy – Poisson traffic)
- A proposed recursive formula for the LEO-MSS (Fixed Channel Reservation (FCR) policy – Poisson traffic)
- Performance measures (FCR policy – Poisson traffic)
- The Threshold Call Admission (TCA) policy

Outline (2)

- A proposed convolution algorithm for the LEO-MSS (TCA policy – Poisson traffic)
- Evaluation – Poisson traffic
- The analytical model for Batched Poisson traffic
- A recursive formula for the LEO-MSS (CS policy – Batched Poisson traffic)
- Performance measures (CS policy – Batched Poisson traffic)
- Evaluation – Batched Poisson traffic
- Applicability of the models in future LEO SDN/NFV enabled satellite networks
- Possible future directions

Definitions (1)

- Low Earth Orbit (LEO)
  - LEO has an altitude range of < 2000 km. The period of a LEO satellite is about 2 hours.
  - We consider the Iridium constellation (66 active satellites evenly distributed, height ~ 780 km, orbital period ~ 100 min).
- Mobile Satellite System (MSS)
  - The MSS is a radio communication system between mobile earth stations and one or more satellites.
  - A MSS can provide multiservice real time applications to a diverse population in large geographical areas.

Definitions (2)

- LEO vs GEO satellite systems
  - LEO MSS have significantly lower transmit power requirements.
  - LEO MSS have significantly lower transmission delays
  - **The expense**: In LEO MSS we have frequent beam handovers (that occur due to the high speed of LEO satellites) to in-service mobile users (MUs).

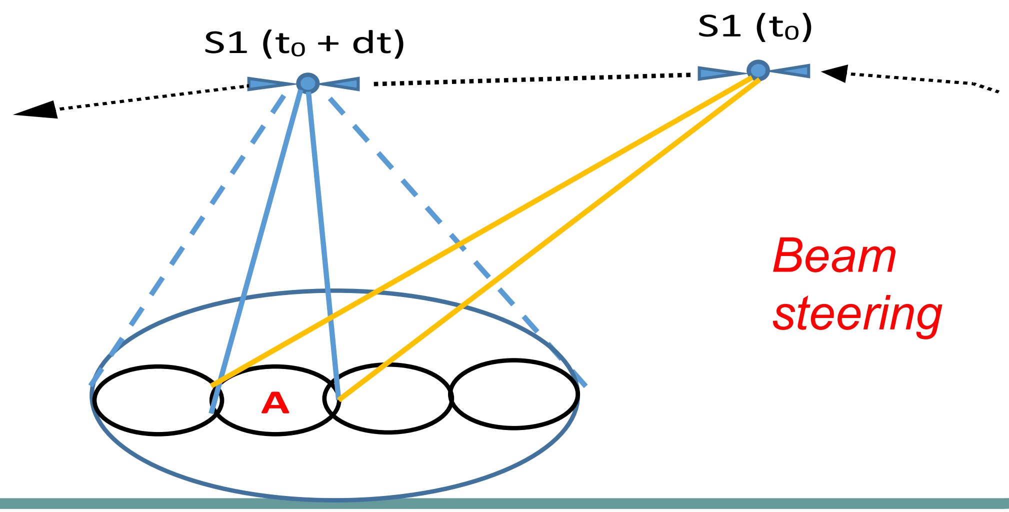
Note: The transfer of an ongoing call from one cell to the next one is named ***beam handover***, and the transfer from a satellite to the next one is named ***satellite handover***.

Definitions (3)

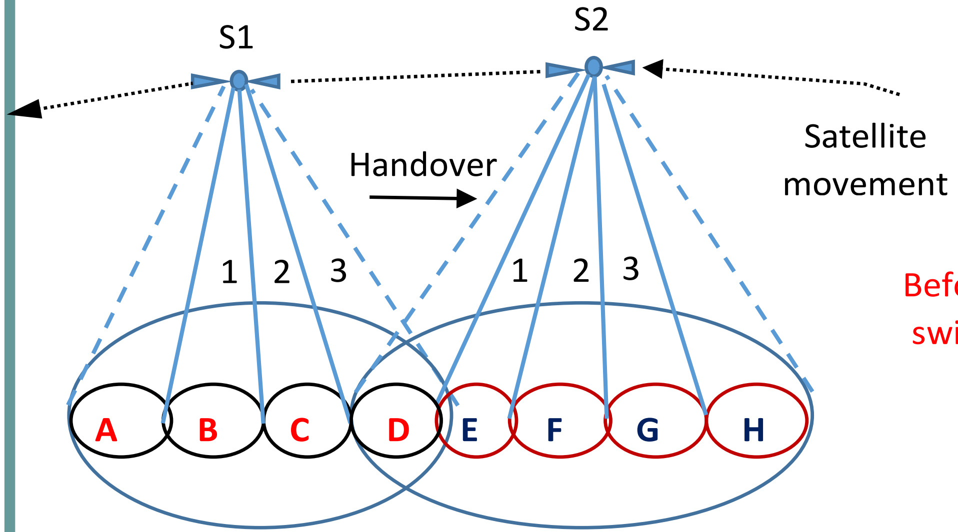
- The footprint of a LEO satellite is divided into several cells.
- Each cell corresponds to a “spot-beam” of the antenna.
- In LEO systems we have two types of coverage:
  - the Earth Fixed-Cell (EFC) coverage
  - the Satellite Fixed-Cell (SFC) coverage (adopted in this tutorial).

Definitions (4)

- **EFC:** the antenna beams are steered so as to point toward a given cell on the earth during some time interval.
  - Handover occurs mainly due to the motion of users.
  - To provide EFC, the satellite should perform: i) beam steering and ii) cell switching (it happens when a beam covering a cell reaches its max. steering angle)

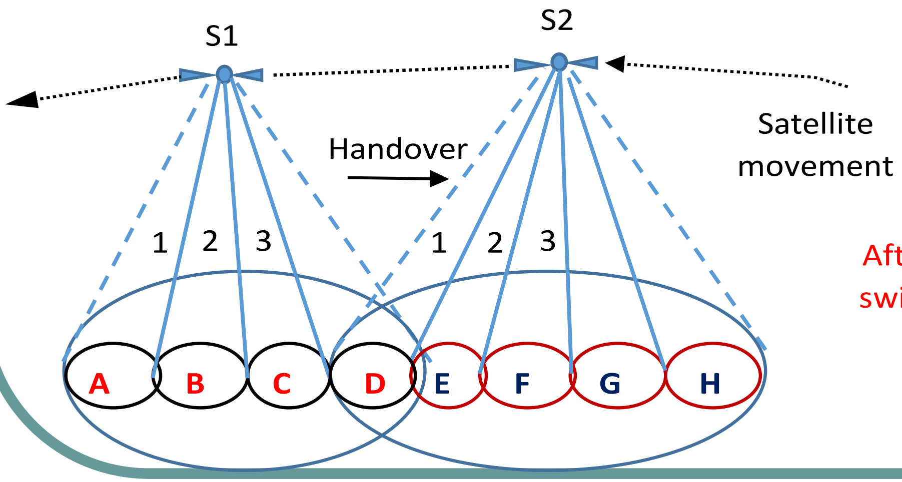


Definitions (5)



Before cell switching

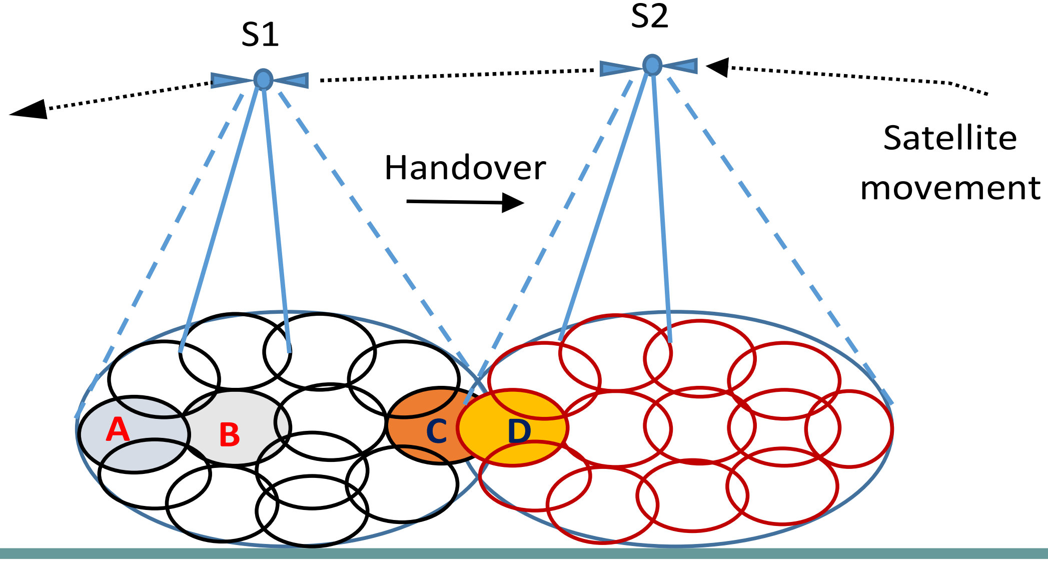
	Before cell switching		After cell switching		Handover type
Cell	Satellite	Beam	Satellite	Beam	
A	*S4*	*3*	*S1*	*1*	*Satellite*
B	S1	1	S1	2	Beam
C	S1	2	S1	3	Beam
D	S1	3	S2	1	Satellite
E	S2	1	S2	2	Beam
F	S2	2	S2	3	Beam
G	*S2*	*3*	*S3*	*1*	*Satellite*
H	*S3*	*1*	*S3*	*2*	*Beam*



After cell switching

Definitions (6)

- **SFC:** Multibeams remain constant relatively to the satellite. The coverage of each beam defines a cell. The cells on the ground move along with the satellite.
  - Handover occurs by the satellite motion (not by the user's motion)
  - Users experience two kinds of handover: 1) beam handover (e.g. from cell A to B) and 2) satellite handover (e.g., from cell C to D)



Definitions (7)

Channel Sharing Policies (1)

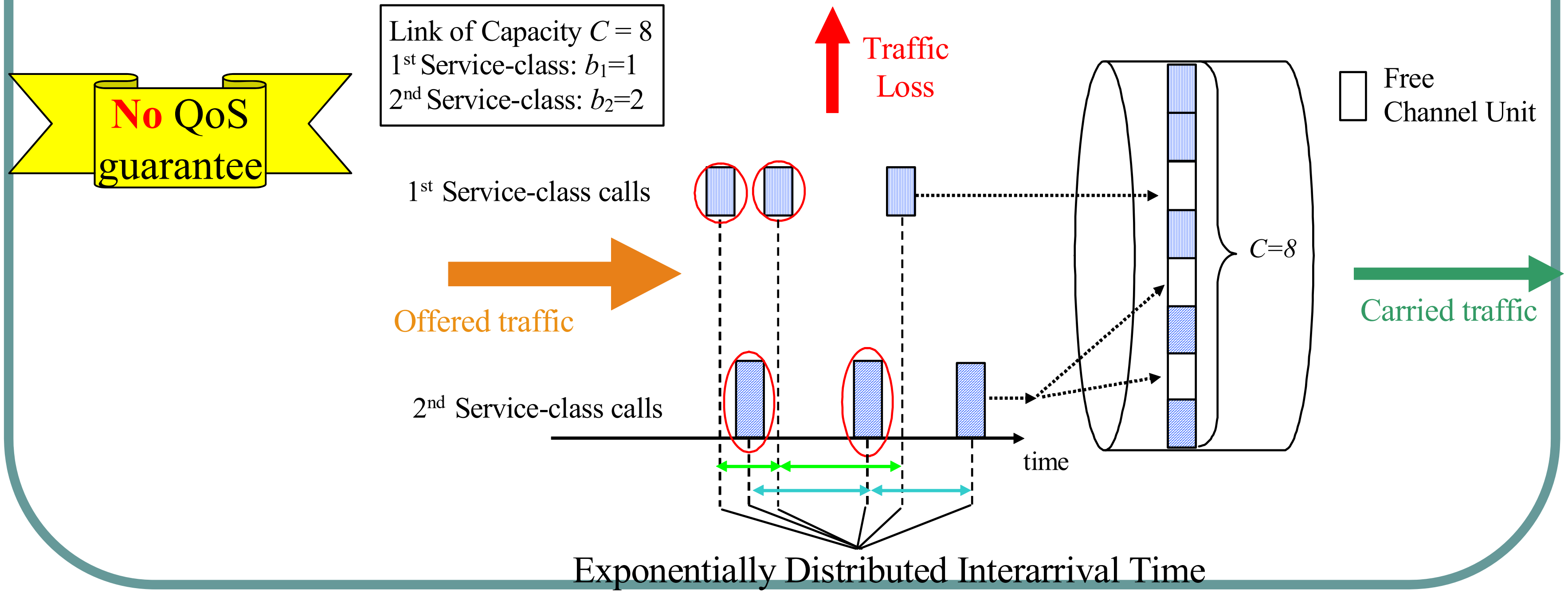
- Considering call-level traffic in a LEO-MSS which accommodates multirate traffic, a QoS mechanism that affects
  - call blocking probabilities (CBP) and
  - handover failure probabilities

  is a channel sharing policy.

Definitions (8)

Channel Sharing Policies (2)

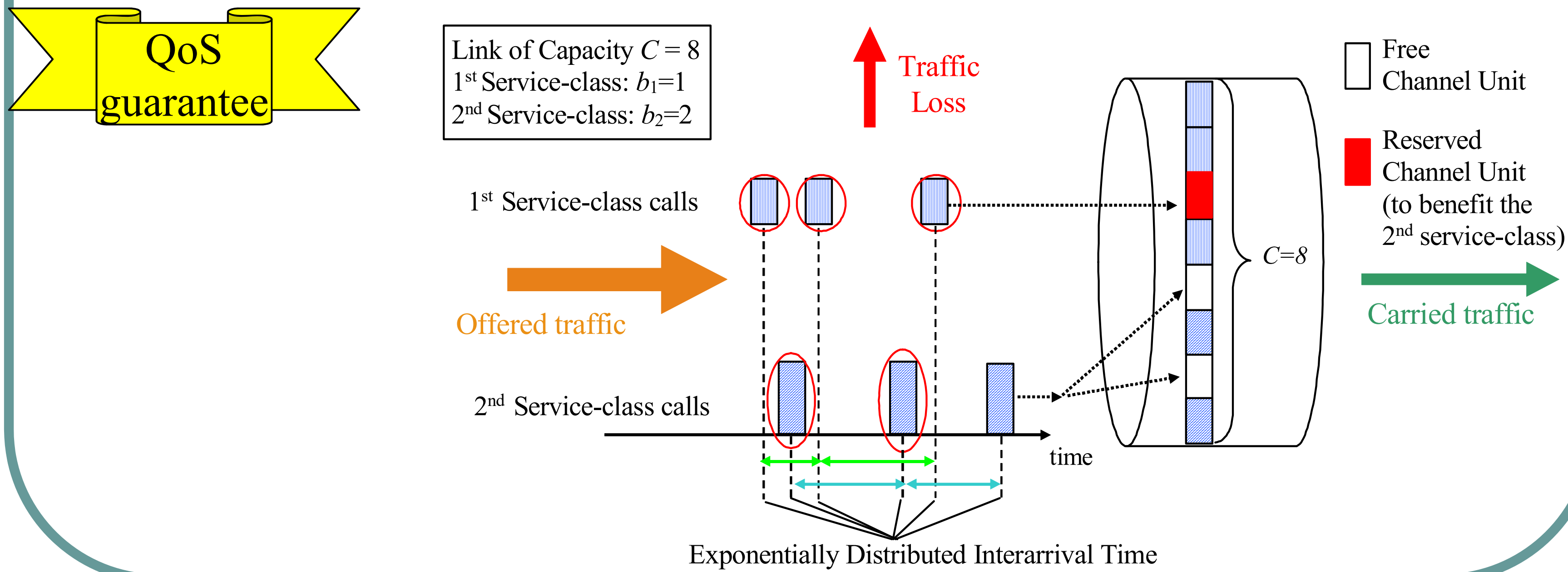
- Complete Sharing (CS) policy: All calls have access to the available channels. A call is accepted in a cell whenever the required channels are available. Otherwise the call is blocked and lost. The CS policy is unfair to calls with high channel requirements since it results in higher CBP.



Definitions (9)

Channel Sharing Policies (3)

- Fixed Channel Reservation (FCR) policy: An integer number of channels is reserved to benefit calls of certain service-classes which have higher channel requirements.



Definitions (10)

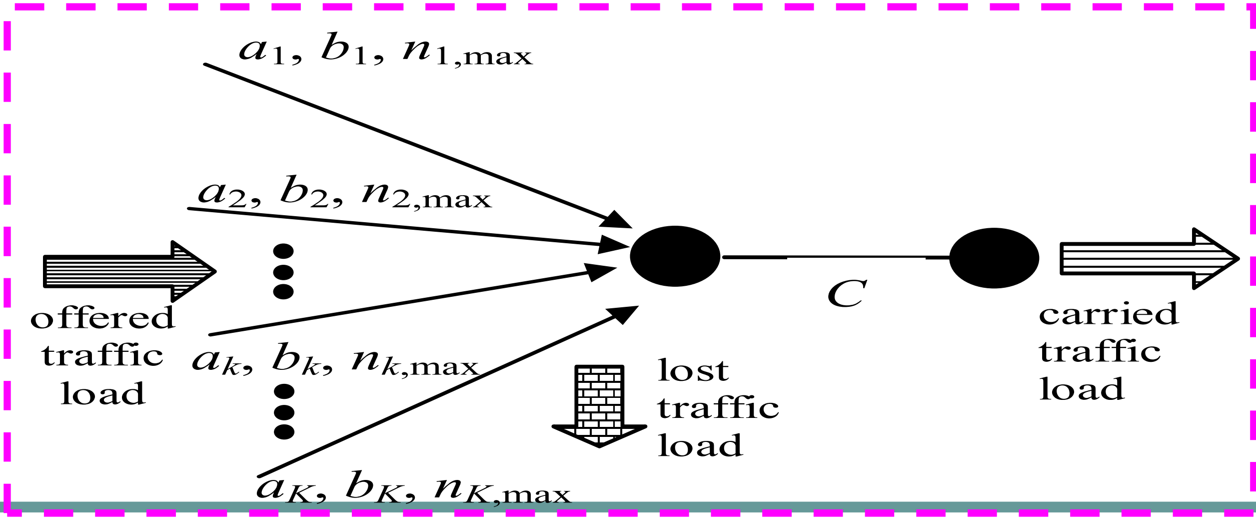
Channel Sharing Policies (4)

- Complete Partitioning (CP) policy: The capacity of a cell is partitioned into *K* subsets (*K* is the number of service-classes accommodated by the system). Each partition, belongs to calls of a certain service-class.
- The CP policy leads to poor channel utilization (so it is not considered herein).

Definitions (11)

Channel Sharing Policies (5)

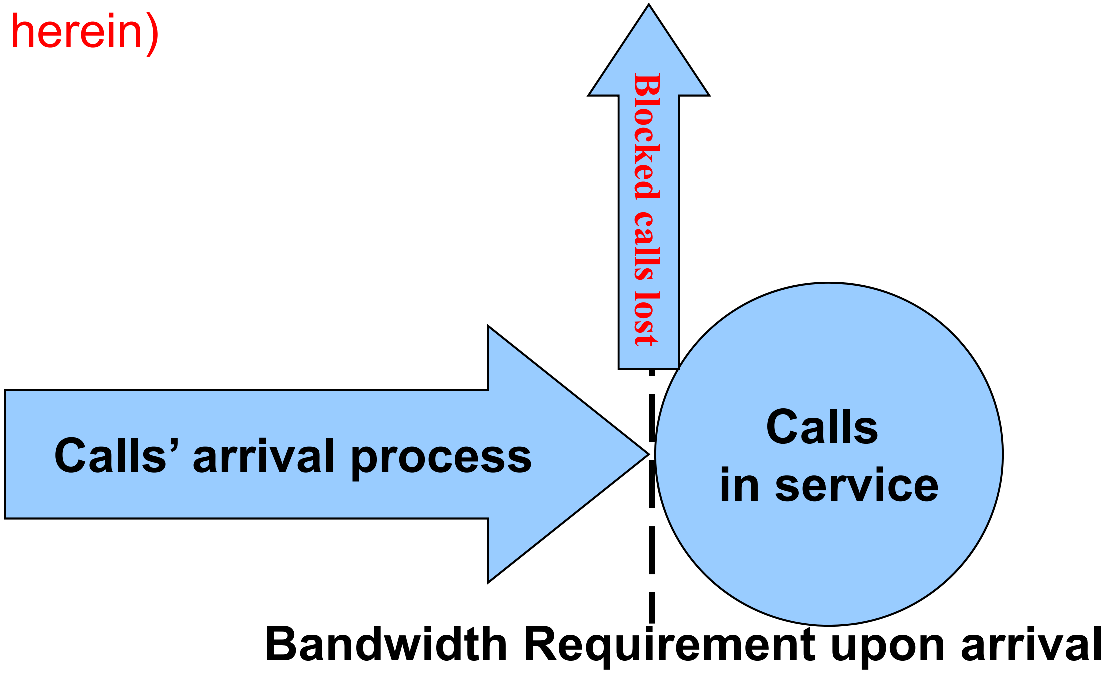
- Threshold Call Admission (TCA) policy: A new service-class *k* call is not accepted in a cell if the number of in-service new and handover service-class *k* calls plus the new call exceeds a threshold (different for each service class).
- The TCA policy is different from the CS and FCR policies since it is based on the number of in-service calls of a service-class AND NOT on the occupied number of channels.



Definitions (12)

Teletraffic Loss Models (1)

- The QoS assessment of LEO-MSS under a channel sharing policy can be accomplished through teletraffic loss or queueing models. (loss models are adopted herein)



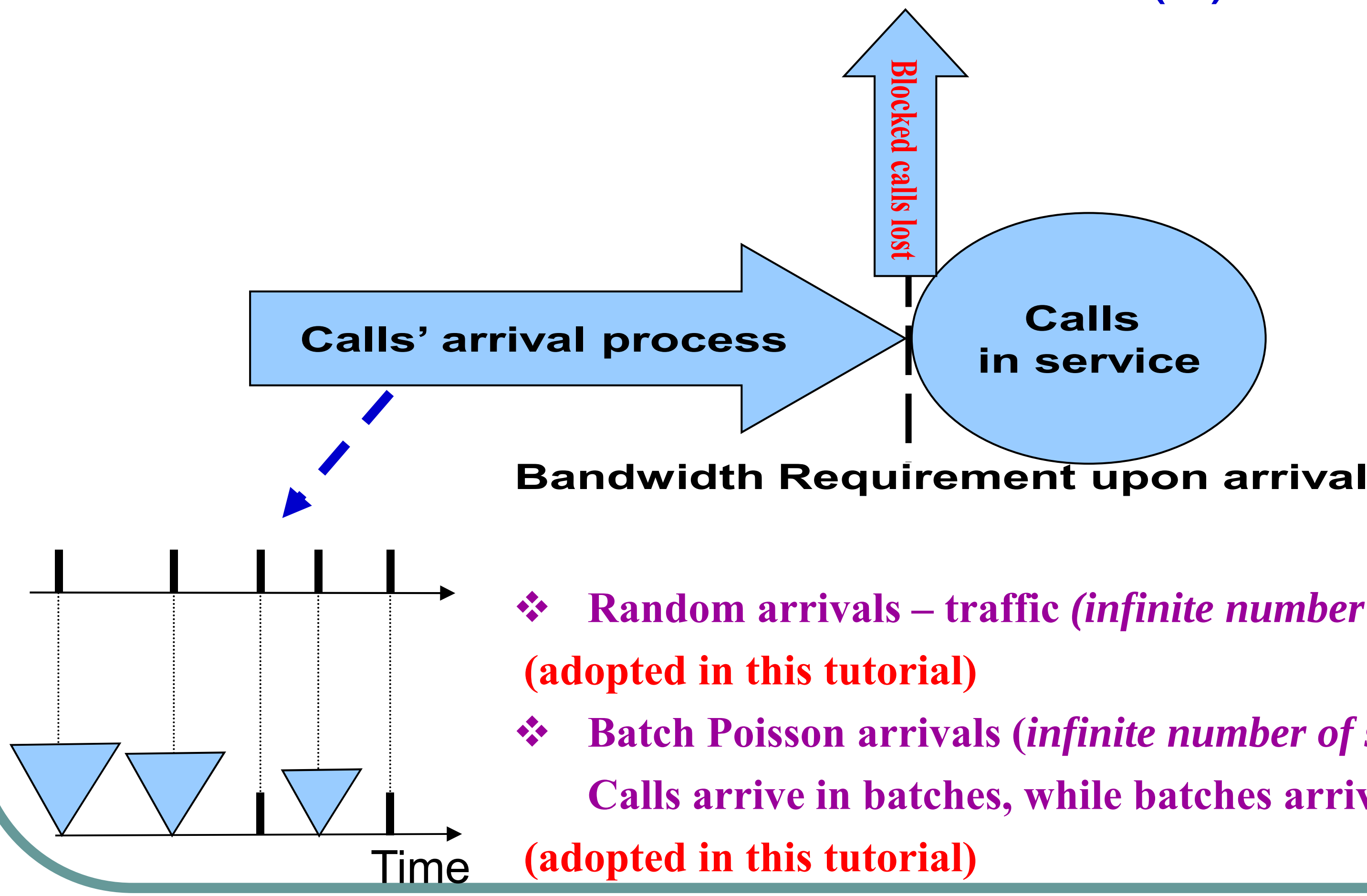
Definitions (13)

Teletraffic Loss Models (2)

- The importance of QoS assessment through teletraffic models
  - Channel allocation among service-classes → QoS Guarantee
  - Avoidance of too costly over-dimensioning of the network
  - Prevention of excessive network throughput degradation, through traffic engineering mechanisms
- The main purpose of teletraffic loss models:
  - The efficient calculation of Call Blocking Probability (CBP) → Recursive formulas

Definitions (14)

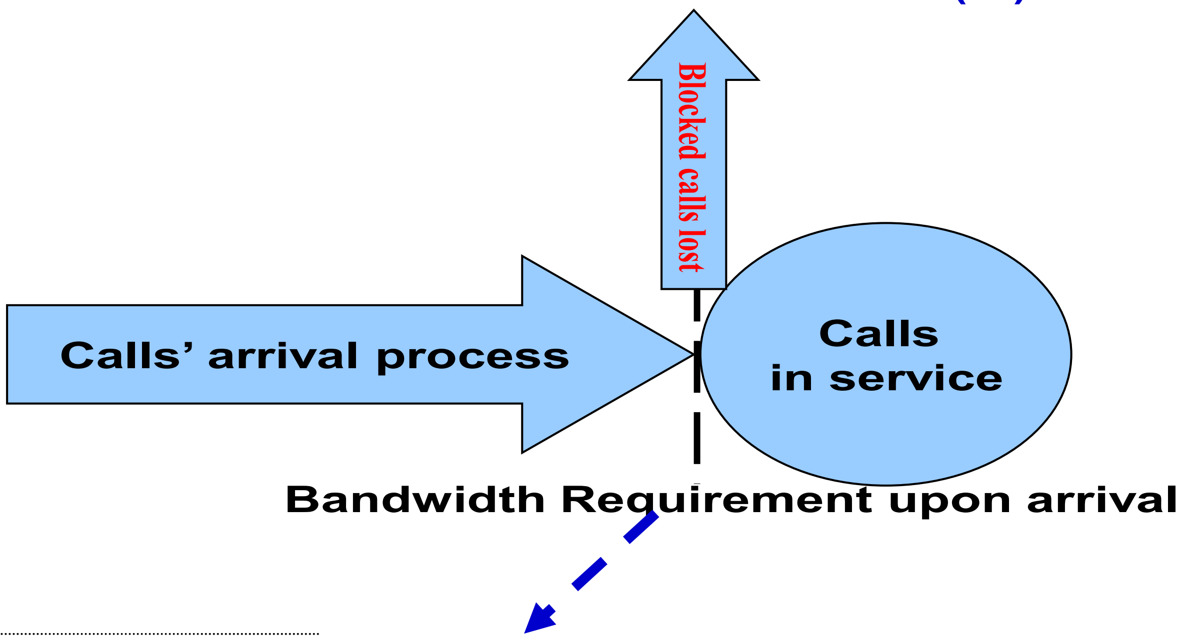
Teletraffic Loss Models (3)



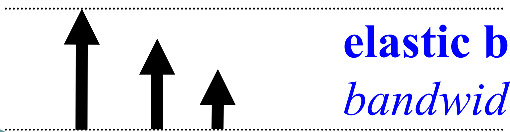
- **Random arrivals – traffic *(infinite number of sources)*.**
  (adopted in this tutorial)
- **Batch Poisson arrivals (*infinite number of sources*).**
  Calls arrive in batches, while batches arrive randomly.
  (adopted in this tutorial)

Definitions (15)

Teletraffic Loss Models (4)



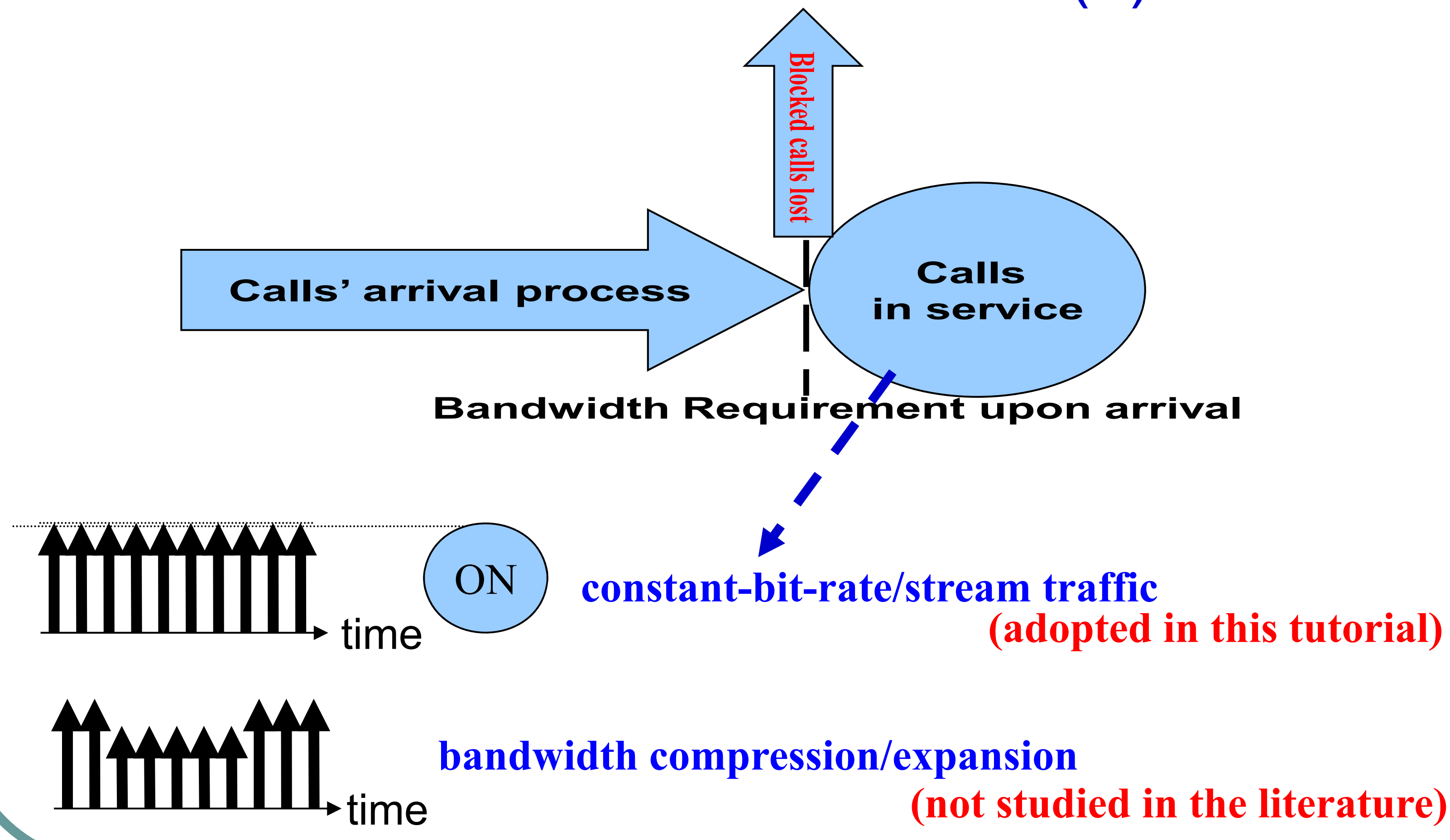
fixed bandwidth **(adopted in this tutorial)**



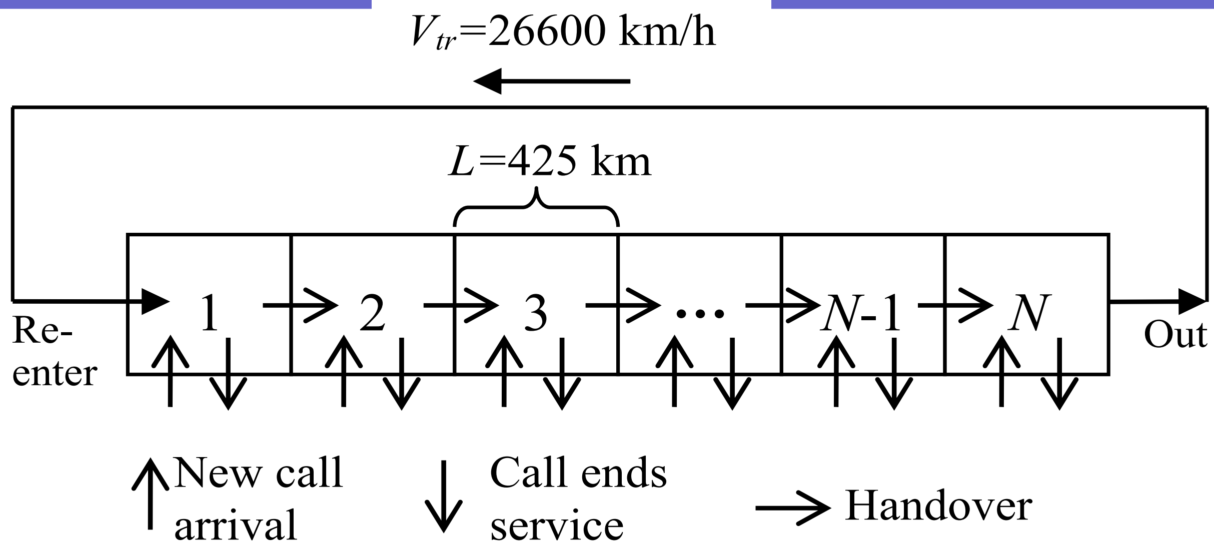
elastic bandwidth: *calls have several, alternative, contingency bandwidth requirements* **(not studied in the literature)**

Definitions (16)

Teletraffic Loss Models (5)

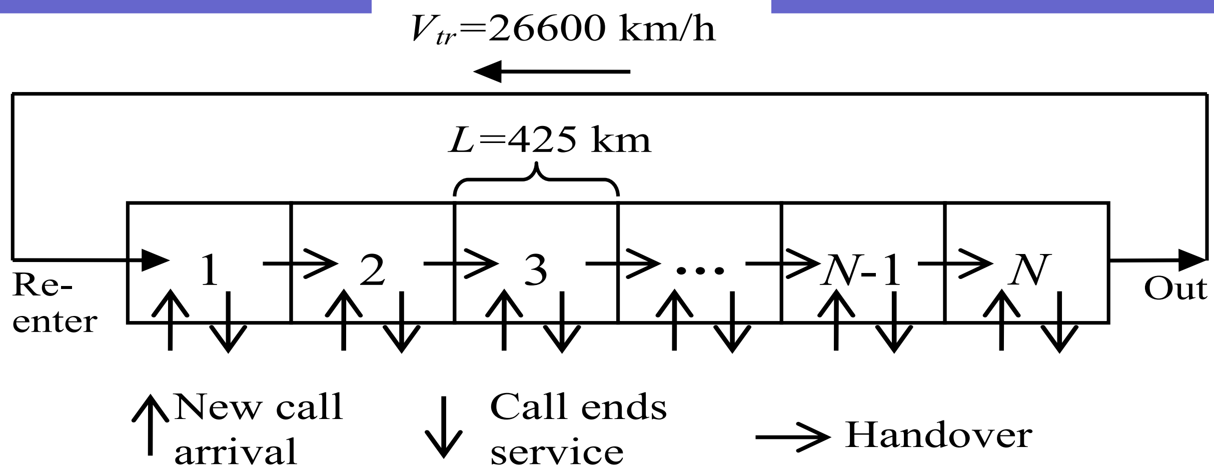


The LEO-MSS model (1)



- N contiguous "satellite-fixed" cells, each modelled as a rectangle of length L = 425 km (in the case of Iridium).
- The cells form a strip of contiguous coverage on the region of the Earth.
- Each cell has a capacity of C channels.
- K different (Poisson) service-classes: call arrival rates λ_k (new) and λ_{hk} (handover) (λ_{hk} **is unknown - should be determined!**)
- Each service-class k (k=1,…,K) call requires b_k channels (fixed requirement)

The LEO-MSS model (2)



- New calls arrive in any cell with equal probability (MUs are uniformly distributed in the system of cells). The cell that a new call originates is the source cell.
- Handover calls move to the adjacent right cell having a velocity of $-V_{tr}$, where V_{tr} (approx. 26600 km/h in Iridium) is the subsatellite point speed. This assumption is valid as long as the rotation of the Earth and the speed of the MU are negligible compared to the subsatellite point speed on the Earth.
- An in-service call that departs from cell *N* requests a handover in cell 1.

The analytical model for Poisson traffic (1)

- Additional definitions

t_c : the dwell time (the time that a call remains in a cell):

(i) uniformly distributed between $[0, L/V_{tr}]$ for new calls in their source cell and (ii) deterministically equal to $T_c = L/V_{tr}$ for handover calls that traverse any adjacent cell from border to border.

T_c: the interarrival time for all handovers subsequent to the first one.

T_{dk} : the duration of a service-class k call in the system (exponentially distributed)

$1/\mu_k$: the channel holding time in a cell (exponentially distributed) (**unknown - should be determined**)

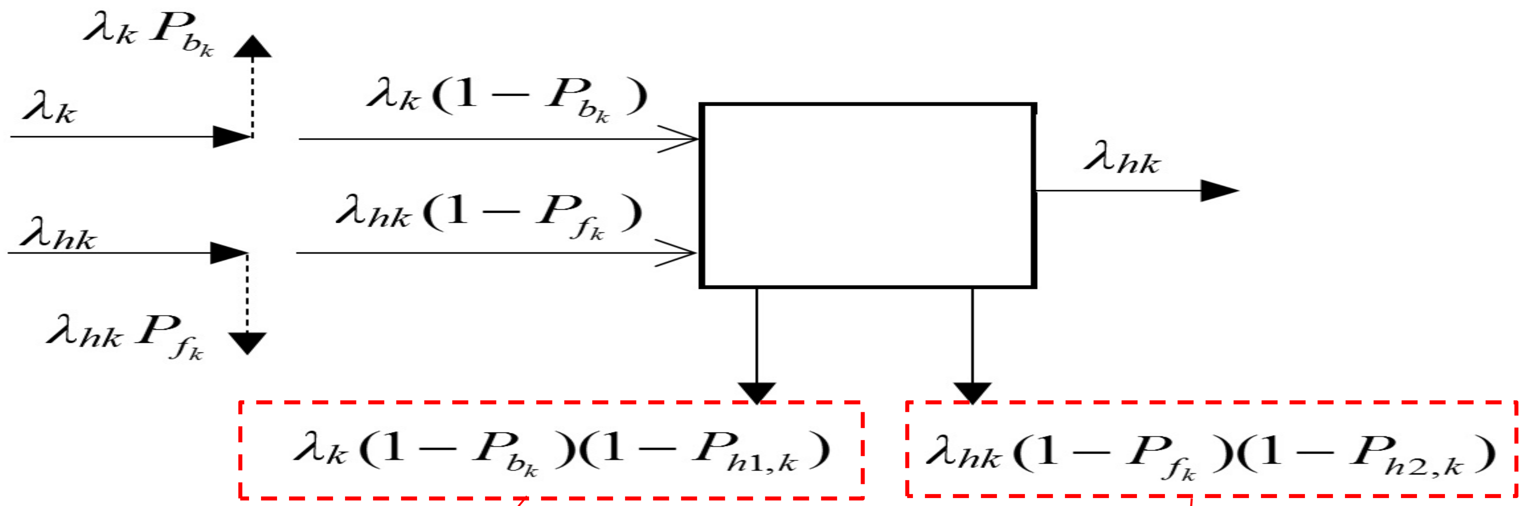
P_{bk}, P_{fk}: Call blocking probability and handover failure probability.

$P_{h1,k}$, $P_{h2,k}$: the handover probability for a service-class k call in the source and in a transit cell, respectively

The analytical model for Poisson traffic (2)

- Determination of the handover arrival rate, λ_{hk}

The handover arrival rate λ_{hk} can be related to λ_k by assuming that in each cell there exists a flow equilibrium between MUs entering and MUs leaving the cell:



new calls that complete their service in the source cell without requesting a handover

handover calls that do not handover to the transit cell

The analytical model for Poisson traffic (3)

- Determination of the handover arrival rate, λ_{hk} (cont.)

$$\boxed{\lambda_k(1-P_{b_k})+\lambda_{hk}(1-P_{f_k})}=\boxed{\lambda_{hk}}+\boxed{\lambda_k(1-P_{b_k})(1-P_{h1,k})}+\boxed{\lambda_{hk}(1-P_{f_k})(1-P_{h2,k})}$$

new and handover calls that are accepted in the cell

calls that are handed over to the transit cell

new calls that complete their service in the source cell without requesting a handover

handover calls that do not handover to the transit cell

$$\frac{\lambda_{hk}}{\lambda_k}=\frac{(1-P_{b_k})P_{h1,k}}{1-(1-P_{f_k})P_{h2,k}}$$

The analytical model for Poisson traffic (4)

- Determination of the mean channel holding time (1)

Reminder: To derive a formula for the channel holding time of service-class *k* calls, we remind that channels are occupied in a cell either by new or handover calls. Furthermore, channels are occupied either until the end of service of a call or until a call is handed over to a transit cell.

$$\mu_k^{-1} = P_k E_k(t_{h1,k}) + P_k^h E_k(t_{h2,k}) = \frac{\lambda_k(1-P_{b_k})E_k(t_{h1,k})}{\lambda_k(1-P_{b_k}) + \lambda_{hk}(1-P_{f_k})} + \frac{\lambda_{hk}(1-P_{f_k})E_k(t_{h2,k})}{\lambda_k(1-P_{b_k}) + \lambda_{hk}(1-P_{f_k})}$$

the probabilities that a channel is occupied by a new and a handover service-class *k* call

$E_k(t_{hi,k})$ is the mean channel holding time in cell i
(if i =1 → source cell, if i=2 → transit cell)

The analytical model for Poisson traffic (5)

- Determination of the mean channel holding time (2)

$$E_k(t_{hi,k}) = T_{dk}(1 - P_{hi,k})$$

T_{dk} : the duration of a service-class *k* call in the system (exp. istributed)
$P_{h1,k}$, $P_{h2,k}$: the handover probability for a service-class *k* call in the source cell and in a transit cell, respectively

$$P_{h1,k} = \int_0^\infty \Pr\{t_{dk} > t \,|\, T_{h1,k} = t\}\, pdf_{T_{h1,k}}(t)dt = \int_0^\infty e^{-t/T_{dk}}\, pdf_{T_{h1,k}}(t)dt = \gamma_k(1 - e^{-(1/\gamma_k)})$$

$$P_{h2,k} = \Pr\left\{t_{dk} > \frac{L}{V_{tr}}\right\} = 1 - \Pr\left\{t_{dk} \le \frac{L}{V_{tr}}\right\} = 1 - \int_0^{T_c} \frac{1}{T_{dk}} e^{-t/T_{dk}} dt = e^{-(1/\gamma_k)}$$

The parameter γ_k, is the ratio between the mean duration of a service-class *k* call in the system and the dwell time of a call in a cell

$$\gamma_k = T_{dk} / T_c$$

A recursive formula for the LEO-MSS (CS policy – Poisson traffic) (1)

The Global Balance equation for state $\boldsymbol{n} = (n_1, n_2, \ldots, n_K)$ is

$$\sum_{k=1}^{K}\left(\lambda_k(\boldsymbol{n}_k^-) + \lambda_{hk}(\boldsymbol{n}_k^-)\right)P(\boldsymbol{n}_k^-) + \sum_{k=1}^{K}(n_k+1)\mu_k P(\boldsymbol{n}_k^+) =$$

$$\sum_{k=1}^{K}\left(\lambda_k(\boldsymbol{n}) + \lambda_{hk}(\boldsymbol{n})\right)P(\boldsymbol{n}) + \sum_{k=1}^{K} n_k \mu_k P(\boldsymbol{n})$$

where n_k is the number of in-service calls of service-class k (k=1,…,K).

The values of $P(\boldsymbol{n})$ can be determined by the Product Form Solution (PFS):

$$P(\boldsymbol{n}) = G^{-1}\left(\prod_{k=1}^{K}\frac{a_k^{n_k}}{n_k!}\right)$$

where G is the normalization constant and $\alpha_k = (\lambda_k + \lambda_{hk})/\mu_k$

A recursive formula for the LEO-MSS (CS policy – Poisson traffic) (2)

Based on the PFS, the following recursive formula can be used for the calculation of the channel occupancy distribution *q*(*j*):

$$q(j) = \begin{cases} 1 \quad for \;\; j = 0 \\ \dfrac{1}{j}\displaystyle\sum_{k=1}^{K} a_k b_k q(j - b_k) \;\; for \;\; j = 1, \ldots, C \\ 0 \; otherwise \end{cases}$$

array q()

0	1	2	3	...	C-4	C-3	C-2	C-1	C

Blocking States, e.g. b_k=4

Z. Wang, P. T. Mathiopoulos and R. Schober, “Performance analysis and improvement methods for channel resource management strategies of LEO-MSS with multiparty traffic”, IEEE Trans. Vehic. Tech., vol. 57, no. 6, pp. 3832-3842, Nov. 2008.

Z. Wang, P. T. Mathiopoulos and R. Schober, “Channeling Partitioning Policies for Multi-Class Traffic in LEO-MSS”, *IEEE Trans. Aerospace and Electronic Systems*, vol. 45, no. 4, pp. 1320-1334, Oct. 2009.

Performance measures (CS policy – Poisson traffic) (1)

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

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

$$P_{f_k} = \delta_k P_{b_k}$$

δ_k is a correction factor introduced in order to model the dependency between successful handovers of a service-class *k* call prior to a handover failure:

$$\delta_k = (1 - P_{b_k}) P_{h1,k} (1 - P_{f_k})^{E_k(n_{hk})-2} P_{h2,k}^{E_k(n_{hk})-2}$$

$$E_k(n_{hk}) = \frac{(1 - P_{b_k}) P_{h1,k}}{1 - (1 - P_{f_k}) P_{h2,k}}$$

$E_k(n_{hk})$ is the average number of times that a new service-class *k* call is successfully handed over during its lifetime in the system

Performance measures (CS policy – Poisson traffic) (2)

Call dropping probability: refers to new calls that are not blocked but they are forced to terminate due to handover failure

$$P_{d_k} = \frac{P_{fk} P_{h1,k}}{1 - P_{h2,k}(1 - P_{fk})}$$

Unsuccessful call probability: refers to calls that they are either blocked in the source cell or dropped due to a handover failure

$$P_{us_k} = P_{b_k} + P_{d_k}(1 - P_{b_k})$$

Z. Wang, P. T. Mathiopoulos and R. Schober, "Performance analysis and improvement methods for channel resource management strategies of LEO-MSS with multiparty traffic", IEEE Trans. Vehic. Tech., vol. 57, no. 6, pp. 3832-3842, Nov. 2008.

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A proposed recursive formula for the LEO-MSS (FCR policy – Poisson traffic) (1)

The FCR policy: A call of service class *k* requests b_k channels and has a FCR parameter CR_k that expresses the integer number of channels reserved to benefit calls of all other service-classes except from *k*.

The Global Balance equation for state $\mathbf{n} = (n_1, n_2, \ldots, n_{2K})$ is

$$\sum_{k=1}^{K} \lambda_k(\mathbf{n}_k^-)P(\mathbf{n}_k^-) + \sum_{k=K+1}^{2K} \lambda_{hk}(\mathbf{n}_k^-)P(\mathbf{n}_k^-) + \sum_{k=1}^{2K} (n_k+1)\mu_k P(\mathbf{n}_k^+) =$$

$$\sum_{k=1}^{K} \lambda_k(\mathbf{n})P(\mathbf{n}) + \sum_{k=K+1}^{2K} \lambda_{hk}(\mathbf{n})P(\mathbf{n}) + \sum_{k=1}^{2K} n_k \mu_k P(\mathbf{n})$$

A service-class *k* call is new if $1 \le k \le K$ and handover if $K+1 \le k \le 2K$

A proposed recursive formula for the LEO-MSS (FCR policy – Poisson traffic) (2)

$$q(j) = \begin{cases} 1 \;\; for \;\; j = 0 \\ \dfrac{1}{j}\displaystyle\sum_{k=1}^{2K} a_k(j-b_k)b_k q(j-b_k) \;\; for \;\; j = 1,\ldots,C \\ 0 \; otherwise \end{cases}$$

$$a_k(j\text{-}b_k) = \begin{cases} a_k \;\; for \;\; j \le C - CR_k \\ 0 \;\; otherwise \end{cases}$$

The formula is approximate since the model does not have a Product Form Solution!

A proposed recursive formula for the LEO-MSS (FCR policy – Poisson traffic) (3)

$K=3,\ b_1 = 1,\ b_2 = 2\ ,\ b_3 = 4$

$CR_1 = 3,\ \ CR_2 = 2,\ \ CR_3 = 0$

Call Blocking equalization

array q()

0	1	2	3	...	C-4	C-3	C-2	C-1	C

1st service-class: blocking states $b_1 + CR_1=4$

2nd service-class: blocking states $b_2 + CR_2=4$

3rd service-class: blocking states $b_3 + CR_3=4$

Performance measures (FCR policy – Poisson traffic)

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

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

$$P_{f_k} = \delta_k P_{b_k}$$

$$P_{d_k} = \frac{P_{fk} P_{h1,k}}{1 - P_{h2,k}(1 - P_{fk})}$$

$$P_{us_k} = P_{b_k} + P_{d_k}(1 - P_{b_k})$$

I. D. Moscholios, V. G. Vassilakis, N. C. Sagias and M. D. Logothetis, "On channel sharing policies in LEO Mobile Satellite Systems", accepted for publication in *IEEE Trans. on Aerospace and Electronic Systems*, DOI: 10.1109/TAES.2018.2798318, Available online: 25 January 2018.

The TCA policy

In the TCA policy, a threshold N_k is defined for each service-class k that denotes the maximum number of new and handover in-service calls of service-class k that are allowed in a cell.

The TCA policy is applied only to new service-class k calls. More precisely, a new service-class k call is accepted in a cell if and only if:

a) there exist available channels, i.e., $j + b_k \leq C$

b) the number of new and handover in-service calls of service-class k plus the new one does not exceed the threshold N_k, i.e., $n_k + 1 \leq N_k$

The last restriction shows that a new call may not be accepted in the cell even if available channels do exist.

Z. Wang, P. T. Mathiopoulos and R. Schober, “Channeling Partitioning Policies for Multi-Class Traffic in LEO-MSS”, *IEEE Trans. Aerospace and Electronic Systems*, vol. 45, no. 4, pp. 1320-1334, Oct. 2009.

Z. Wang, D. Makrakis and H. Mouftah, “Performance Analysis of Threshold Call Admission Policy for Multi-class Traffic in Low Earth Orbit Mobile Satellite Systems”, Proc. SPACOMM, Athens, Greece, June 2010.

A proposed convolution algorithm for the LEO-MSS (TCA policy – Poisson traffic) (1)

The TCA model can be described by the following PFS:

$$P(\boldsymbol{n}) = G^{-1}\left(\prod_{k=1}^{K} \frac{x_k^{n_k}}{n_k\,!}\right)$$

with

$$\frac{x_k^{n_k}}{n_k\,!} = \begin{cases} \dfrac{a_k^{n_k}}{n_k\,!} & \text{if } n_k \le N_k \\[2ex] \dfrac{a_{kn}^{N_k}\, a_{kh}^{(n_k - N_k)}}{n_k\,!} & \text{if } n_k > N_k \end{cases}$$

$$a_k = (\lambda_k + \lambda_{hk}) / \mu_k = a_{kn} + a_{kh}$$

$$a_{kn} = \lambda_k \,/\, \mu_k \qquad a_{kh} = \lambda_{hk} \,/\, \mu_k$$

I. D. Moscholios, V. G. Vassilakis, N. C. Sagias and M. D. Logothetis, "On channel sharing policies in LEO Mobile Satellite Systems", accepted for publication in *IEEE Trans. on Aerospace and Electronic Systems*, DOI: 10.1109/TAES.2018.2798318, Available online: 25 January 2018.

A proposed convolution algorithm for the LEO-MSS (TCA policy – Poisson traffic) (2)

For an efficient calculation of the various performance measures we can exploit the PFS of the TCA model, and use the following 3-step convolution algorithm:

Step 1: Determine the channel occupancy distribution $q_k(j)$ of each service-class k (k=1,…,K), assuming that only service-class k exists in the system:

$$q_k(j) = \begin{cases} q_k(0)\dfrac{a_k^{n_k}}{n_k!} & \text{for } n_k \le N_k \text{ and } j = n_k b_k \\ q_k(0)\dfrac{a_{kn}^{N_k} a_{kh}^{(n_k - N_k)}}{n_k!} & \text{for } n_k > N_k \text{ and } j = n_k b_k \end{cases}$$

A proposed convolution algorithm for the LEO-MSS (TCA policy – Poisson traffic) (3)

Step 2: Determine the aggregated occupancy distribution $Q_{(-k)}$ based on the successive convolution of all service-classes apart from service-class *k*:

$$Q_{(-k)} = q_1 * \ldots * q_{k-1} * q_{k+1} * \ldots * q_K$$

By the term "successive" we mean that initially q_1 and q_2 should be convolved in order to obtain q_{12}. Then we convolve q_{12} with q_3 to obtain q_{123} etc. The convolution operation between two occupancy distributions of service-class *k* and *r* is defined as:

$$q_k * q_r = \left\{ q_k(0)q_r(0), \sum_{m=0}^{1} q_k(m)q_r(1-m), \ldots, \sum_{m=0}^{C} q_k(m)q_r(C-m) \right\}$$

A proposed convolution algorithm for the LEO-MSS (TCA policy – Poisson traffic) (4)

Step 3: Calculate the CBP of service-class *k* based on the convolution operation of Q(-k) (step 2) and q_k (step 1) as follows:

$$Q_{(-k)} * q_k = \left\{ Q_{(-k)}(0) q_k(0), \sum_{m=0}^{1} Q_{(-k)}(m) q_k(1-m), ..., \sum_{m=0}^{C} Q_{(-k)}(m) q_k(C-m) \right\}$$

Normalizing the values of the previous formula, we obtain the channel occupancy distribution $q(j)$, j=0,1,…,C via:

$$q(0) = Q_{(-k)}(0) q_k(0) / G$$

$$q(j) = \left(\sum_{m=0}^{j} Q_{(-k)}(m) q_k(j-m) \right) \Big/ G, \; j = 1, ..., C$$

I. D. Moscholios, V. G. Vassilakis, N. C. Sagias and M. D. Logothetis, “On channel sharing policies in LEO Mobile Satellite Systems”, accepted for publication in *IEEE Trans. on Aerospace and Electronic Systems*, DOI: 10.1109/TAES.2018.2798318, Available online: 25 January 2018.

Performance measures (TCA policy – Poisson traffic)

$$P_{b_k} = \sum_{j=C-b_k+1}^{C} q(j) + \sum_{x=N_k b_k}^{C-b_k} q_k(x) \sum_{y=x}^{C-b_k} Q_{(-k)}(C-b_k-y)$$

The 1st term expresses those states *j* where there are no available channels for service-class *k* calls. The 2nd term refers to states where there are available channels for service-class *k* calls but call blocking occurs (for new calls) due to the TCA policy.

$$P_{f_k} = \delta_k P_{b_k}$$

$$P_{d_k} = \frac{P_{fk} P_{h1,k}}{1 - P_{h2,k}(1 - P_{fk})}$$

$$P_{us_k} = P_{b_k} + P_{d_k}(1 - P_{b_k})$$

Evaluation – Poisson traffic (1)

Assumptions

- The simulated network consists of N = 7 contiguous cells.
- The subsatellite point speed is V_{tr} = 26600 km/h and the length of each cell is L = 425 km
- Max. dwell time of a call in a cell is equal to 57.5 s.
- MUs are uniformly distributed in the network of cells and new calls may arrive anywhere within the network.
- No distortion in the propagation links is considered.
- Simscript III simulation language.
- Simulation results are mean values of 7 runs.
- In each run, twenty million calls are generated.
- The blocking events of the first 3% of the generated calls are excluded.

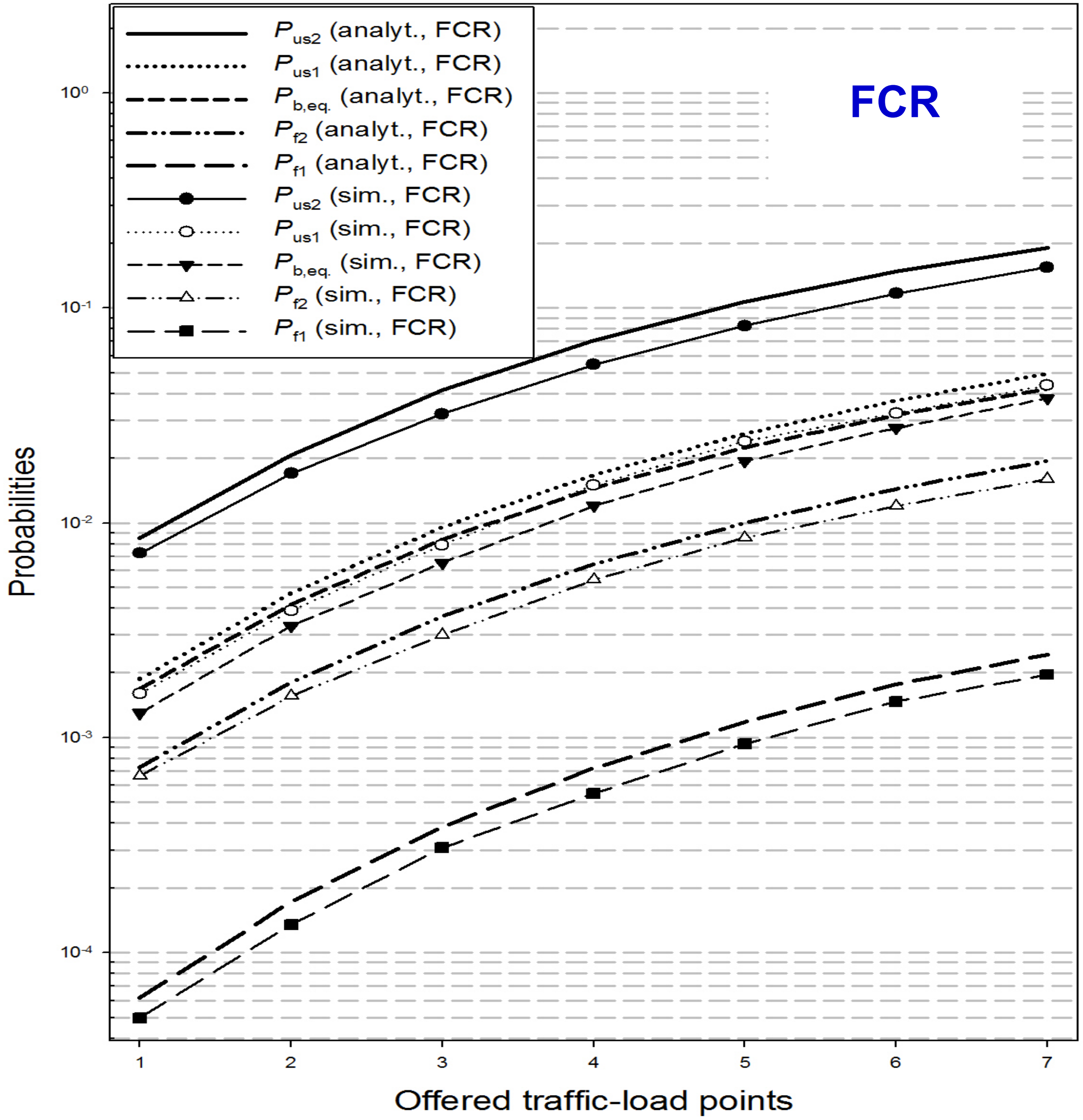
Evaluation – Poisson traffic (2)

First example

- Each cell has a capacity of C = 40 channels.
- K = 2 service-classes
- b_1 = 1 and b_2 = 5 channels
- T_{d1} = 180 s, T_{d2} = 540 s
- α_1 = 16 erl and α_2 = 0.4 erl (per cell).
- FCR parameters (for new calls): CR_1 = 4 and CR_2 = 0 channels. This selection achieves CBP equalization among new calls since $b_1 + CR_1 = b_2$.
- In the case of the TCA policy, we consider two sets of thresholds: 1) N_1 =30, N_2 =3 and 2) N_1 =38, N_2 =3 calls.

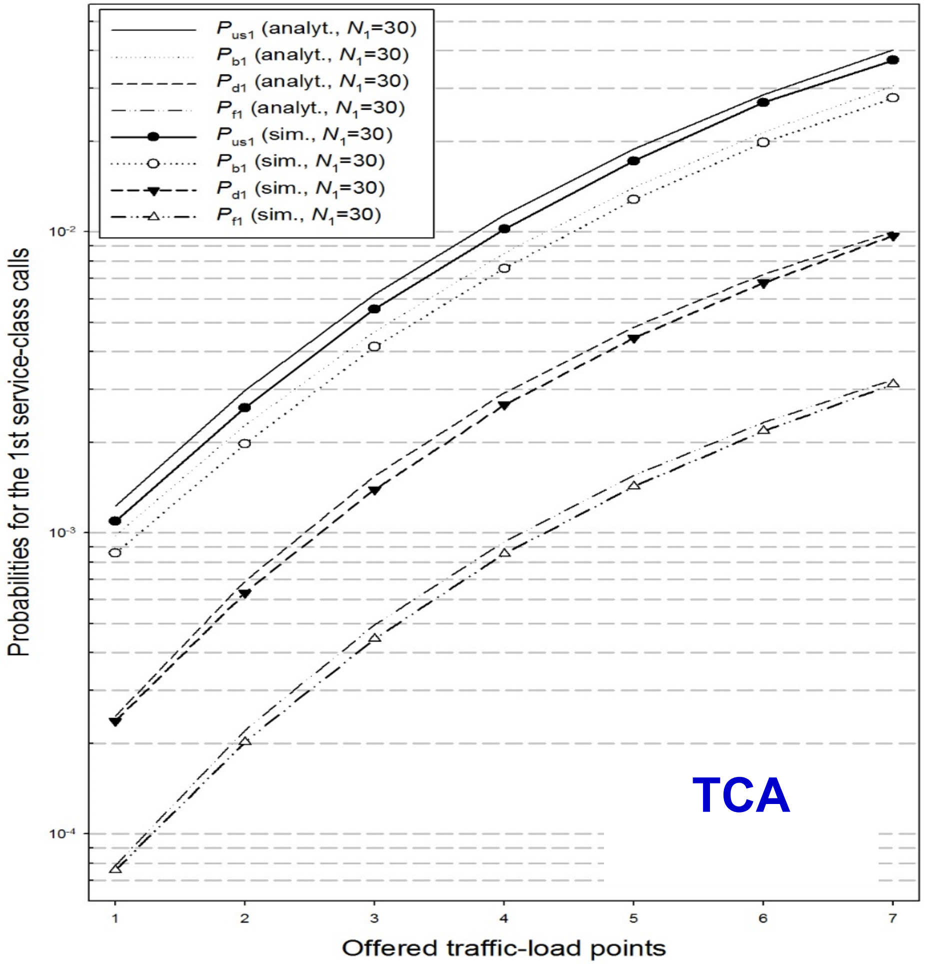
Evaluation – Poisson traffic (3)

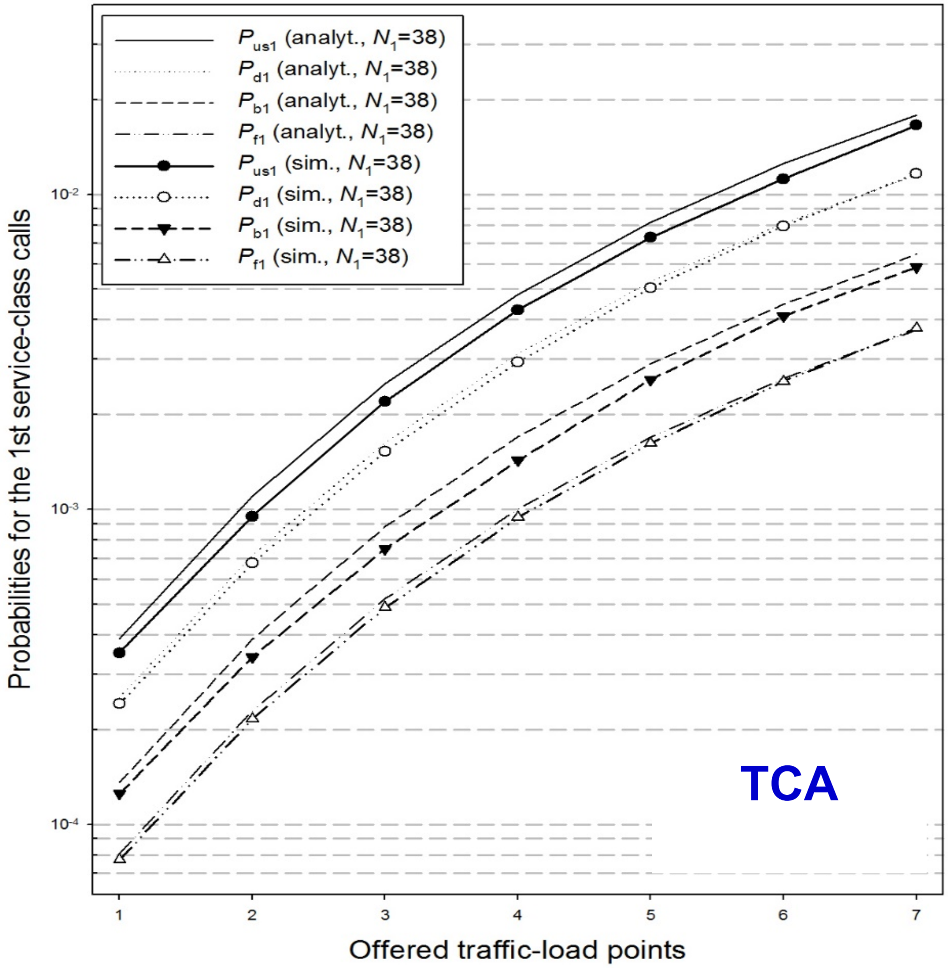
In the x-axis the traffic loads α_1 and α_2 increase in steps of 1 and 0.1 erl, respectively.



Evaluation – Poisson traffic (4)

Increasing N_1 from 30 to 38 calls, decreases the CBP but increases the handover failure probs and the call dropping probs. This is expected since more new calls of the 1st service-class are allowed to enter the system.





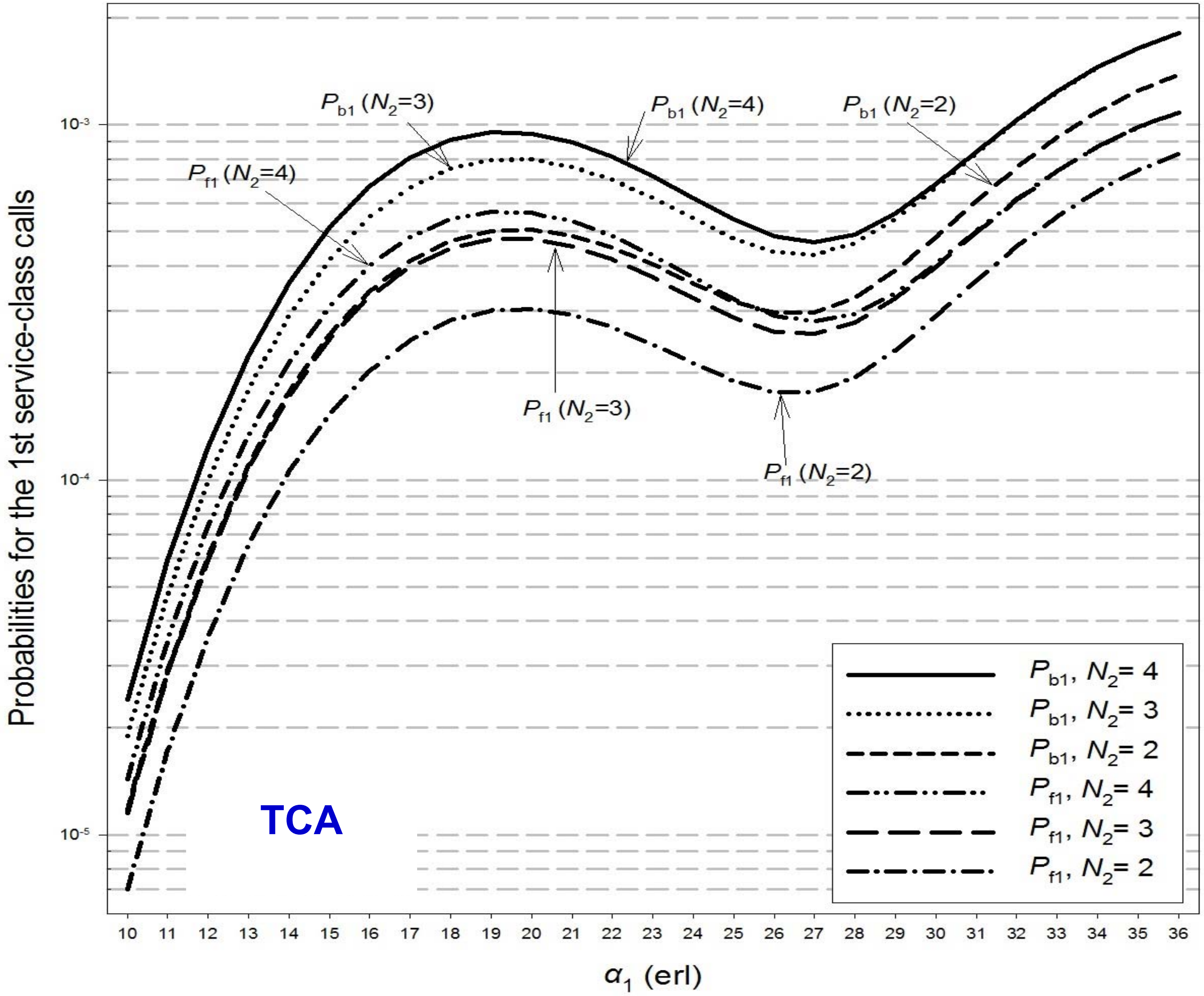
Evaluation – Poisson traffic (5)

Second example

- Each cell has a capacity of C = 100 channels.
- K = 2 service-classes
- b_1 = 1 and b_2 = 20 channels
- T_{d1} = 180 s, T_{d2} = 540 s
- α_1 = 10 erl and α_2 = 1.0 erl (per cell).
- In the case of the TCA policy, we consider two sets of thresholds: 1) N_1 = 70, N_2 = 2, 2) N_1=70, N_2=3 and 3) N_1=70, N_2=4 calls.

Evaluation – Poisson traffic (6)

We see oscillations of the CBP and handover failure probabilities



Evaluation – Poisson traffic (7)

To intuitively explain such oscillations, consider an instant where a new call of the 1st service-class arrives in a cell and finds 20 available channels.

- ✓ In that case, the call is accepted and the cell has 19 available channels.

If now a new call of the 2nd service-class arrives in the cell it will be blocked, leaving the 19 channels for calls (new or handover) of the 1st service-class.

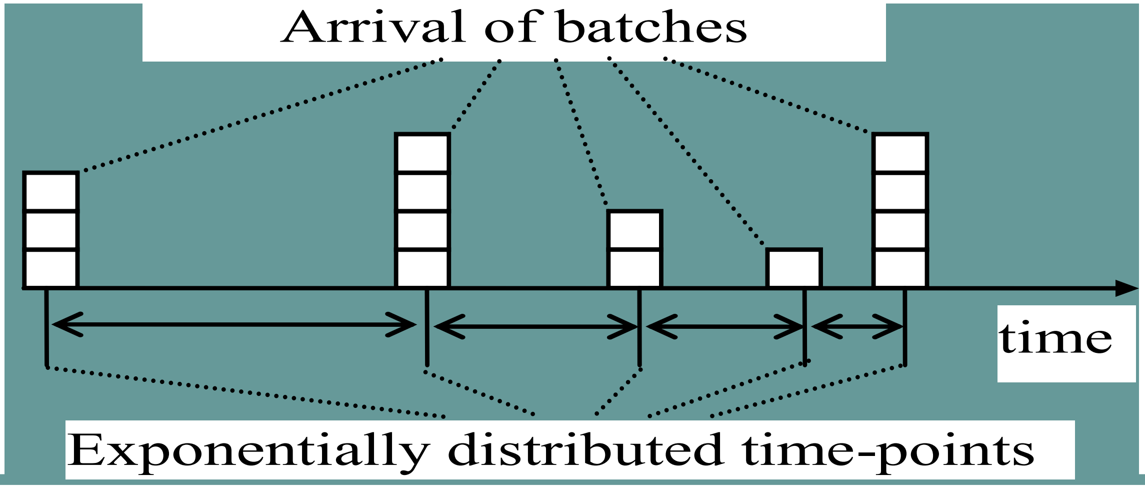
- ✓ In such a case, an increase in α_1 will not lead to a CBP or handover failure probabilities increase.

As α_1 continues to increase, the corresponding probabilities of the 1st service-class calls will increase until another block of 19 channels becomes available to 1st service-class calls.

The analytical model for Batched Poisson traffic (1a)

Assumptions

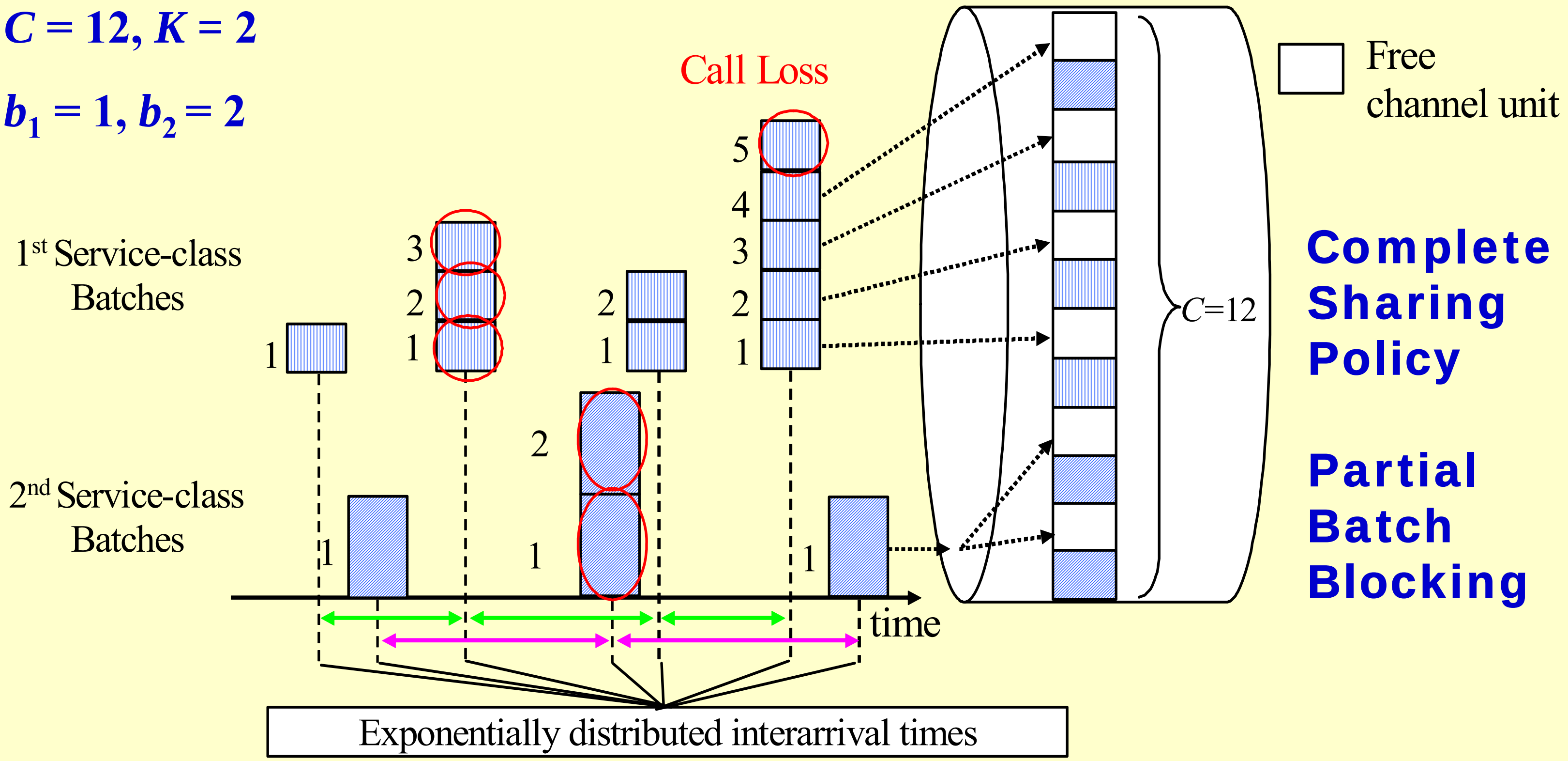
1) New and handover calls follow the Batched Poisson process.
2) The batch size is generally distributed (in the results we consider the geometric batch size distribution)
3) The partial batch blocking discipline is considered (Calls of a new batch are treated separately from the rest ones, which means that one or more calls of a batch can be accepted in the system, while the rest can be blocked and lost, due to lack of available channels)



The analytical model for Batched Poisson traffic (1b)

$C = 12, K = 2$

$b_1 = 1, b_2 = 2$



Complete Sharing Policy

Partial Batch Blocking

The analytical model for Batched Poisson traffic (2)

λ_k batch arrival rate for new calls

λ_{hk} batch arrival rate for handover calls

$B_m^{(k)}$ probability that there are *m* calls in an arriving batch of new service-class *k* calls

$B_m^{(hk)}$ probability that there are *m* calls in an arriving batch of handover service-class *k* calls

The analytical model for Batched Poisson traffic (3)

- Determination of the handover arrival rate, λ_{hk}

$$\frac{\lambda_{hk}}{\lambda_k} = \frac{(1-P_{b_k})P_{h1,k}}{1-(1-P_{f_k})P_{h2,k}}$$

- Determination of the channel holding time

$$\mu_k^{-1} = P_k E_k(t_{h1,k}) + P_k^h E_k(t_{h2,k}) = \frac{\lambda_k(1-P_{b_k})E_k(t_{h1,k})}{\lambda_k(1-P_{b_k}) + \lambda_{hk}(1-P_{f_k})} + \frac{\lambda_{hk}(1-P_{f_k})E_k(t_{h2,k})}{\lambda_k(1-P_{b_k}) + \lambda_{hk}(1-P_{f_k})}$$

The analytical model for Batched Poisson traffic (4)

The values of $P(\boldsymbol{n})$ can be determined by the Product Form Solution (PFS):

$$P_{\boldsymbol{n}} = G^{-1}\left(\prod_{k=1}^{2K} P_{n_k}^{(k)}\right)$$

$$P_{n_k}^{(k)} = \begin{cases} \sum_{l=1}^{n_k} a_k \dfrac{P_{n_k-l}^{(k)} B_{c,l-1}^{(k)}}{n_k}, & for\ n_k \geq 1\ and\ k = 1,\ldots,K \\ \sum_{l=1}^{n_k} a_{hk} \dfrac{P_{n_k-l}^{(k)} B_{c,l-1}^{(hk)}}{n_k}, & for\ n_k \geq 1\ and\ k = K+1,\ldots,2K \\ 1, & for\ n_k = 0\ and\ k = 1,\ldots,2K \end{cases}$$

A recursive formula for the LEO-MSS (CS policy – Batched Poisson traffic)

Based on the PFS, the following recursive formula can be used for the calculation of the channel occupancy distribution $q(j)$:

$$\underbrace{\sum_{k=1}^{K} a_k b_k \sum_{l=1}^{\lfloor j/b_k \rfloor} q(j - l \times b_k) B_{c,l-1}^{(k)}}_{\text{New calls}} + \underbrace{\sum_{k=1}^{K} a_{hk} b_k \sum_{l=1}^{\lfloor j/b_k \rfloor} q(j - l \times b_k) B_{c,l-1}^{(hk)}}_{\text{Handover calls}} = j q(j)$$

I. D. Moscholios, V. G. Vassilakis, P. G. Sarigiannidis, N. C. Sagias and M. D. Logothetis, "An analytical framework in LEO Mobile Satellite Systems Servicing Batched Poisson Traffic", *IET Communications*, vol. 12, issue 1, pp. 18-25, January 2018.

Performance measures (CS policy – Batched Poisson traffic)

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

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

$$P_{f_k} = \delta_k P_{b_k}$$

$$P_{d_k} = \frac{P_{fk} P_{h1,k}}{1 - P_{h2,k}(1 - P_{fk})}$$

$$P_{us_k} = P_{b_k} + P_{d_k}(1 - P_{b_k})$$

Evaluation – Batched Poisson traffic (1)

Assumptions

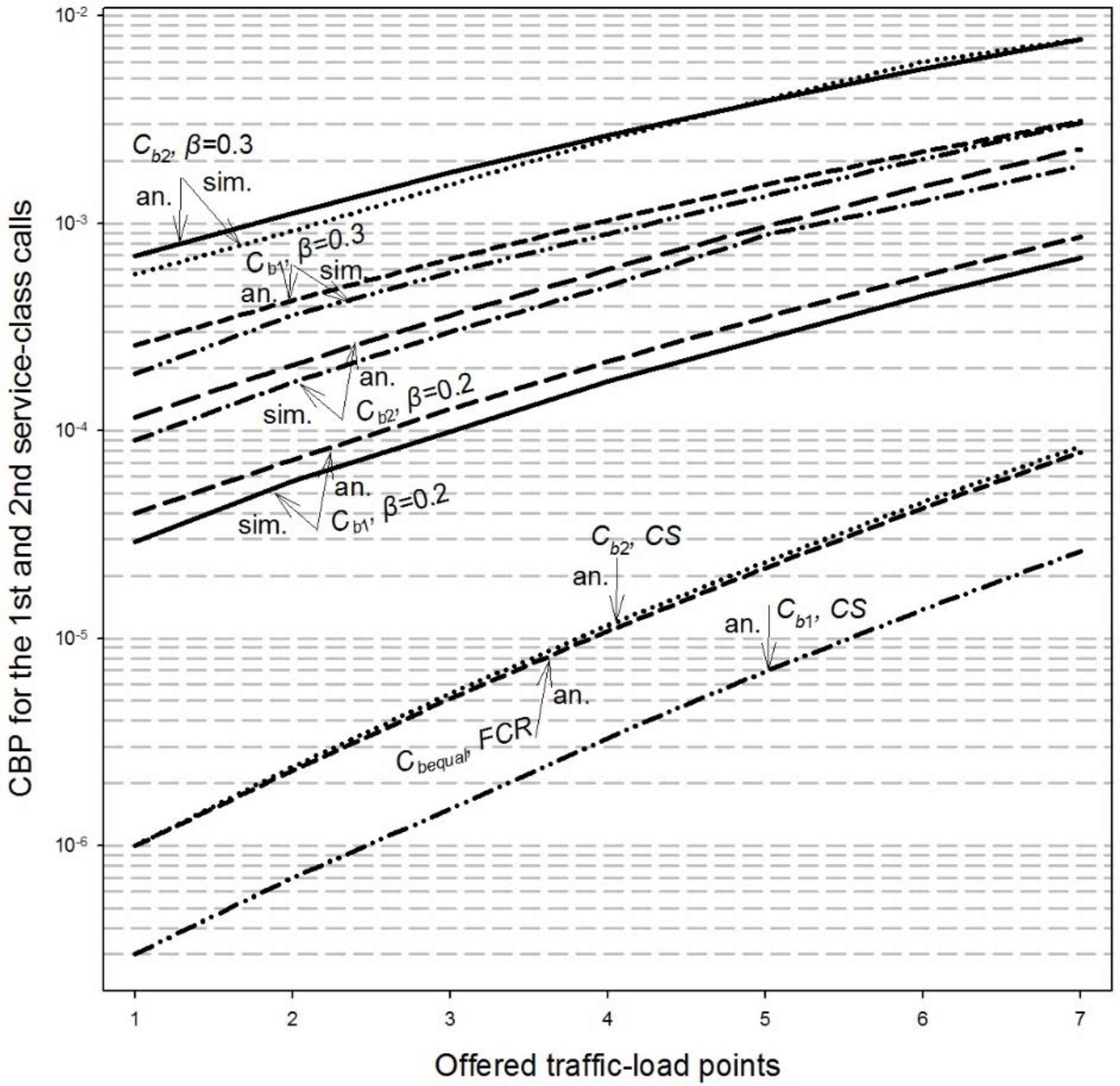
- The simulated network consists of N = 7 contiguous cells.
- The subsatellite point speed is V_{tr} = 26600 km/h and the length of each cell is L = 425 km
- Max. dwell time of a call in a cell equal to 57.5 s.
- MUs are uniformly distributed in the network of cells and new calls may arrive anywhere within the network.
- No distortion in the propagation links is considered.
- Simscript III simulation language.
- Simulation results are mean values of 7 runs.
- In each run, twenty million calls are generated.
- The blocking events of the first 3% of the generated calls are excluded.

Evaluation – Batched Poisson traffic (2)

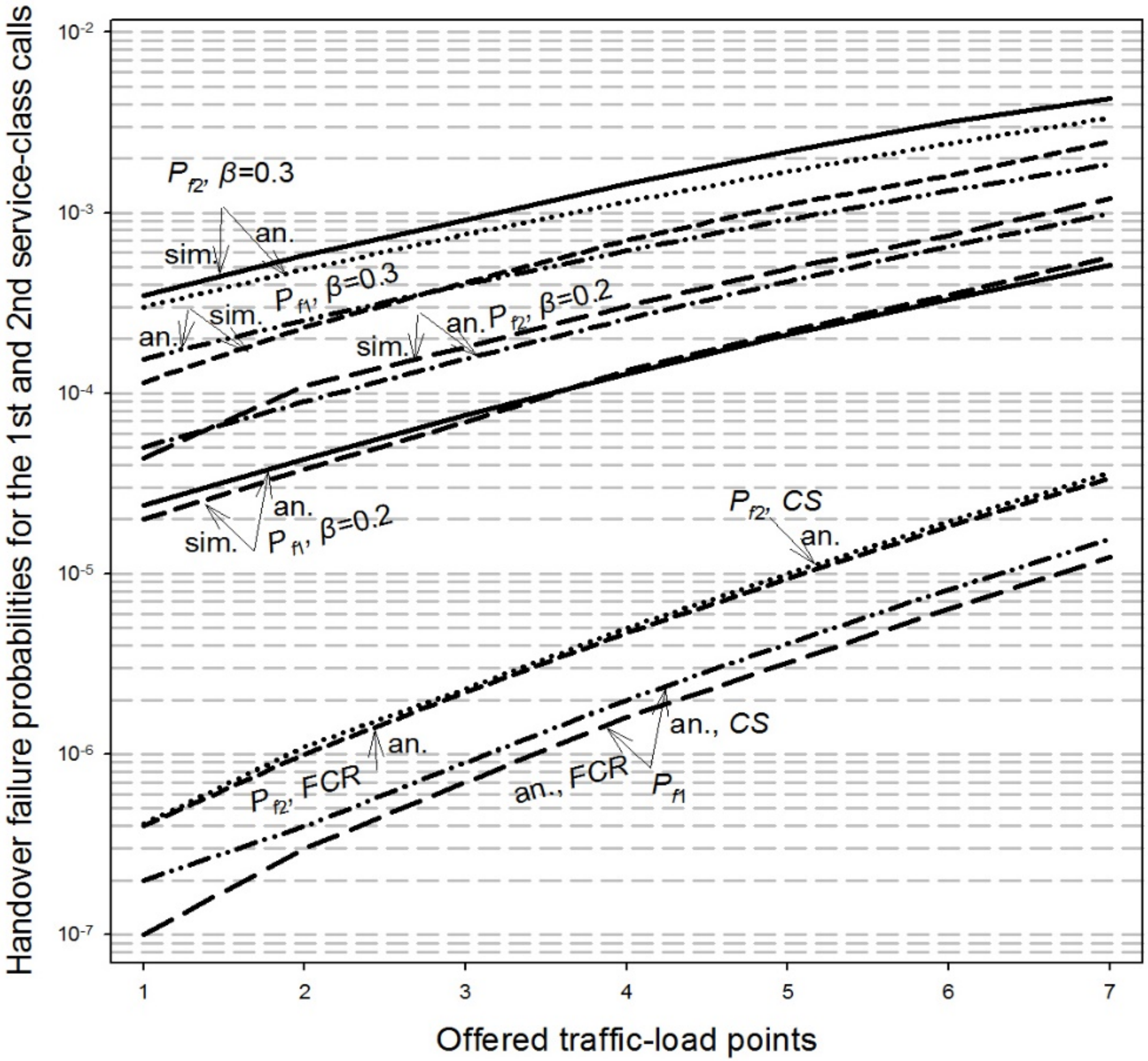
Example

- Each cell has a capacity of C = 30 channels.
- K = 2 service-classes
- b_1 = 1 and b_2 = 2 channels
- T_{d1} = 180 s, T_{d2} = 540 s
- α_1 = 9 erl and α_2 = 0.33 erl (per cell).
- Batch size: geometrically distributed. Two different sets are considered: 1) $\beta_1 = \beta_2 = 0.2$ and 2) $\beta_1 = \beta_2 = 0.3$.
- FCR parameters (for new calls): CR_1 = 1 and CR_2 = 0 channels. This selection achieves CBP equalization among new calls since $b_1 + CR_1 = b_2$.
- In the x-axis the traffic loads α_1 and α_2 increase in steps of 0.5 and 0.05 erl, respectively.

Evaluation – Batched Poisson traffic (3)



Evaluation – Batched Poisson traffic (4)



Evaluation – Batched Poisson traffic (5)

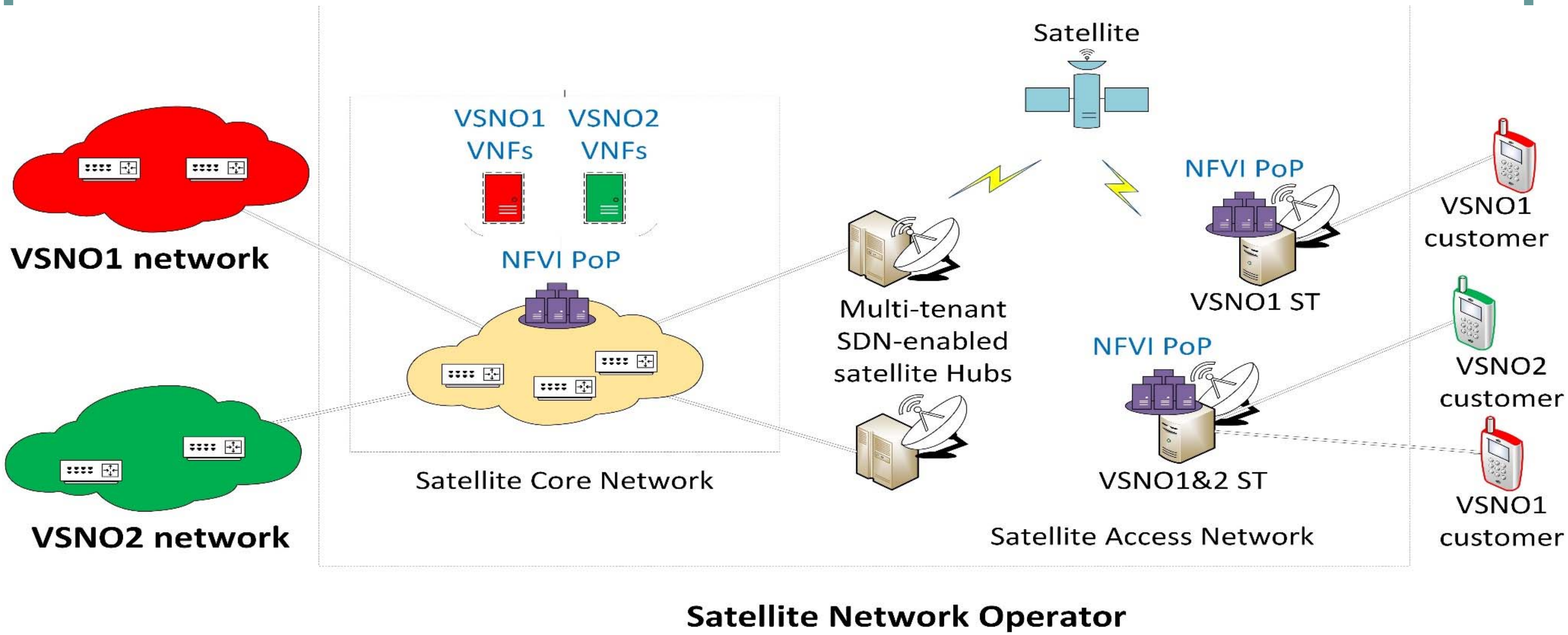
- The batched Poisson process clearly results in much higher probability results compared to the corresponding results assuming the classical Poisson process.
- An increase in the parameter β of the geometrical distribution results in an increase of the corresponding performance measures since the average number of calls in the arriving batches increases.

Applicability of the models in future LEO SDN/NFV enabled satellite networks (1)

Our considered SDN/NFV satellite network architecture is presented below. This is in line with the architecture proposed by the EC H2020 VITAL project.

In the fig., a satellite network operator (SNO) owns an SDN/NFV infrastructure that enables multi-tenancy. This means that the SNO may have multiple virtual SNOs (VSNOs) as its customers.

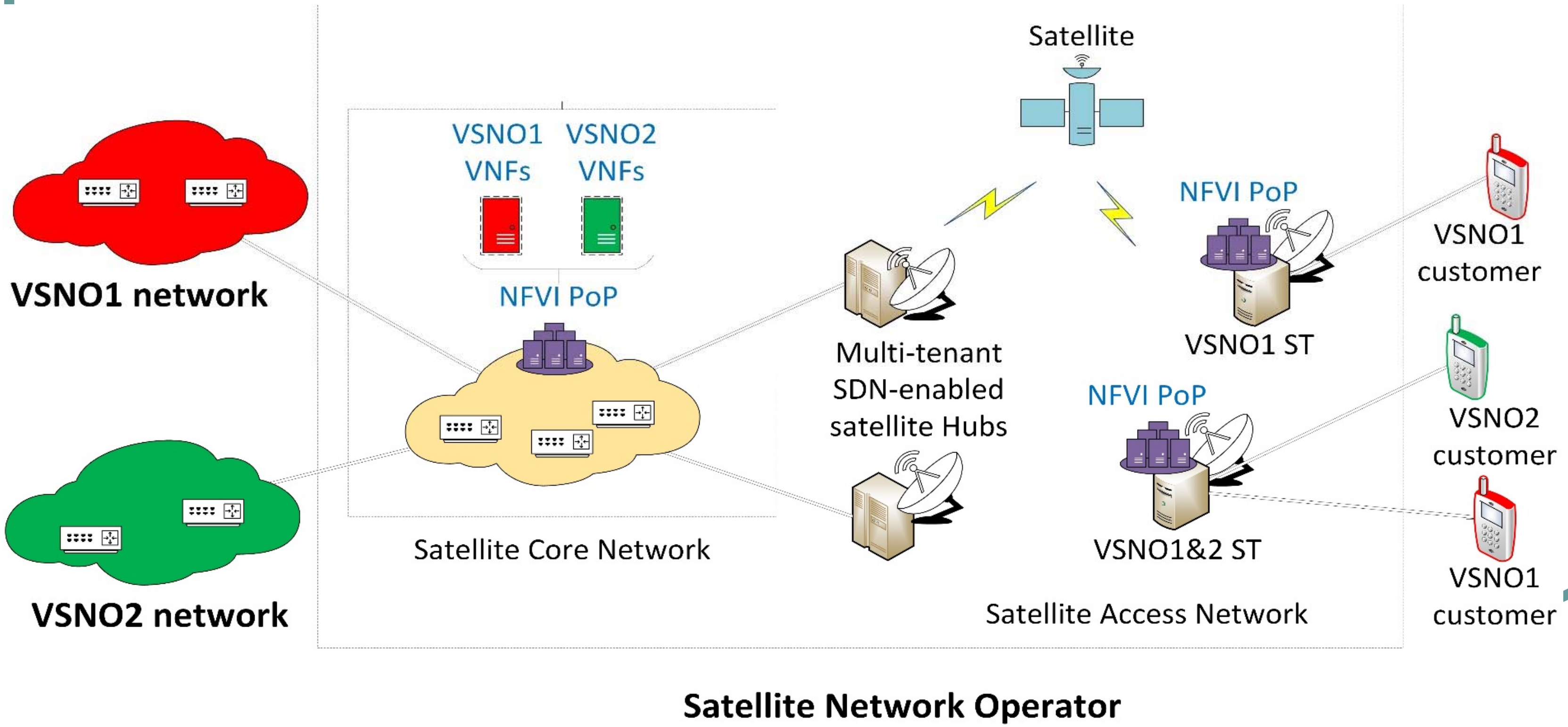
The benefit for the VSNOs is that they can offer satellite services to their customers without owing any physical infrastructure.



Applicability of the models in future LEO SDN/NFV enabled satellite networks (2)

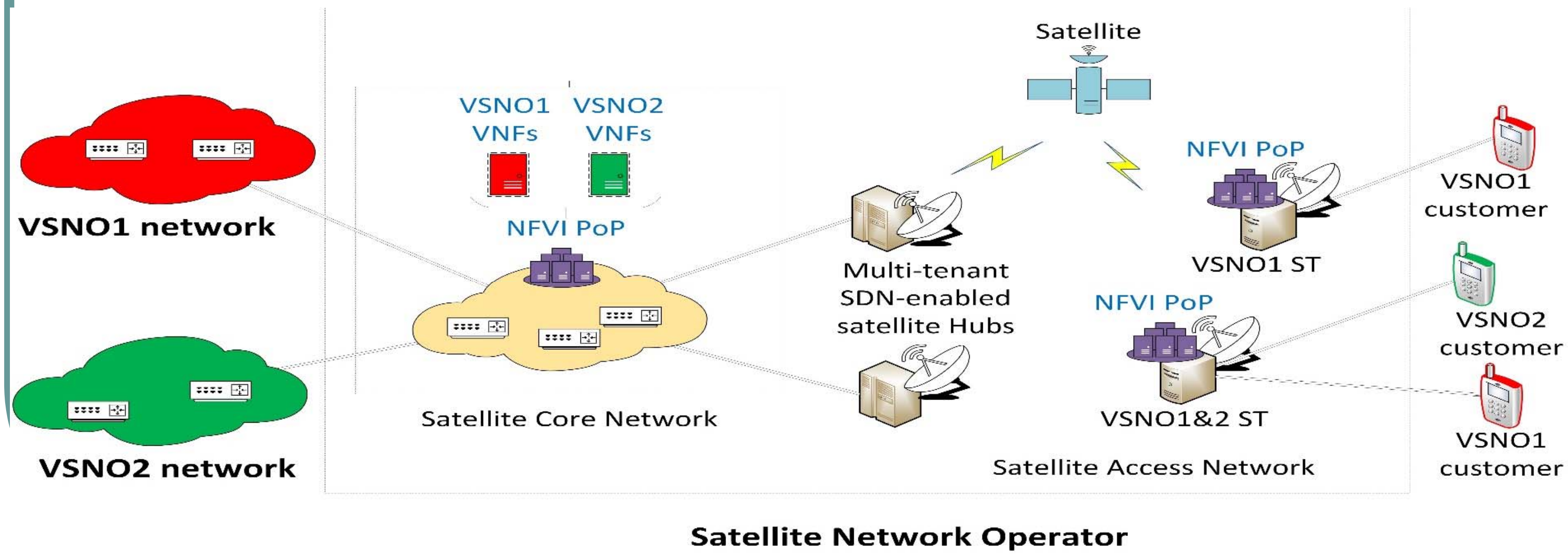
The considered architecture consists of the following four parts:

- Control and management systems (not shown in the Fig.). These include the network control center (NCC) and the network management center (NMC). The NCC provides real-time control of the satellite network, while the NMC is responsible for the management of the system elements in the network.



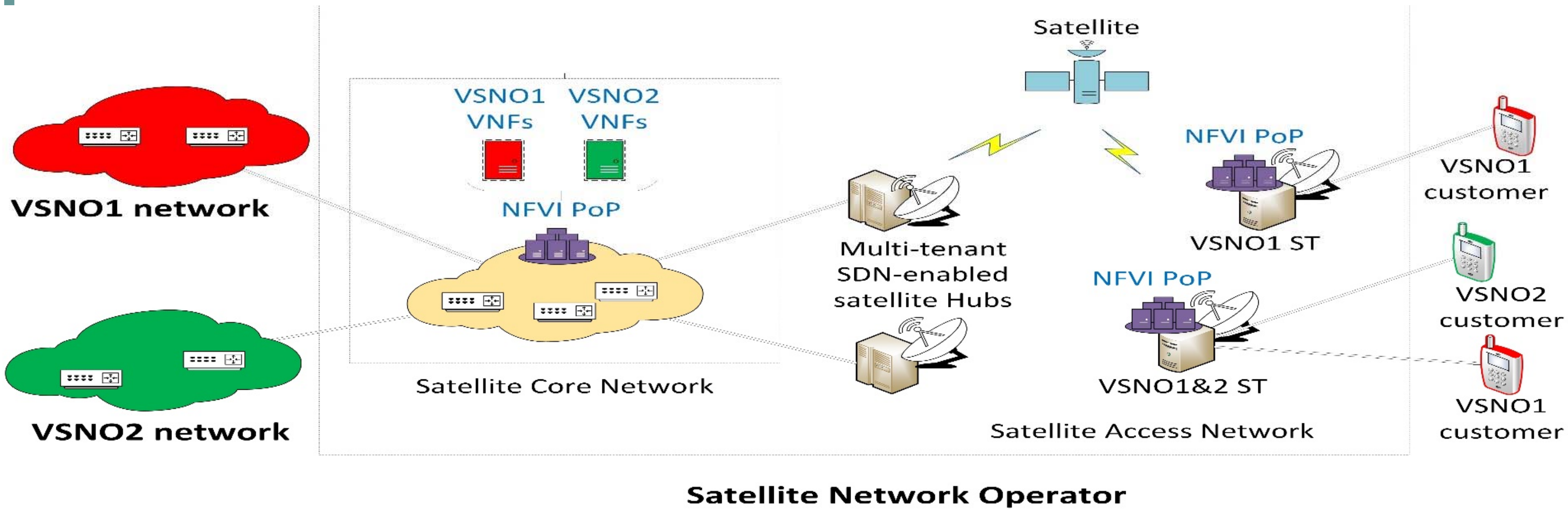
Applicability of the models in future LEO SDN/NFV enabled satellite networks (3)

- Satellite core network. This connects the SNO's access network to the VSNOs' networks. The satellite core network includes NFV infrastructure (NFVI) points of presence (PoPs). On top of the NFVI, different tenants (i.e., VSNO1 and VSNO2 in this example) are able to install and operate their own virtual network functions (VNFs). Example of such VNFs are load balancers, firewalls, deep packet inspection (DPI) systems, etc.



Applicability of the models in future LEO SDN/NFV enabled satellite networks (4)

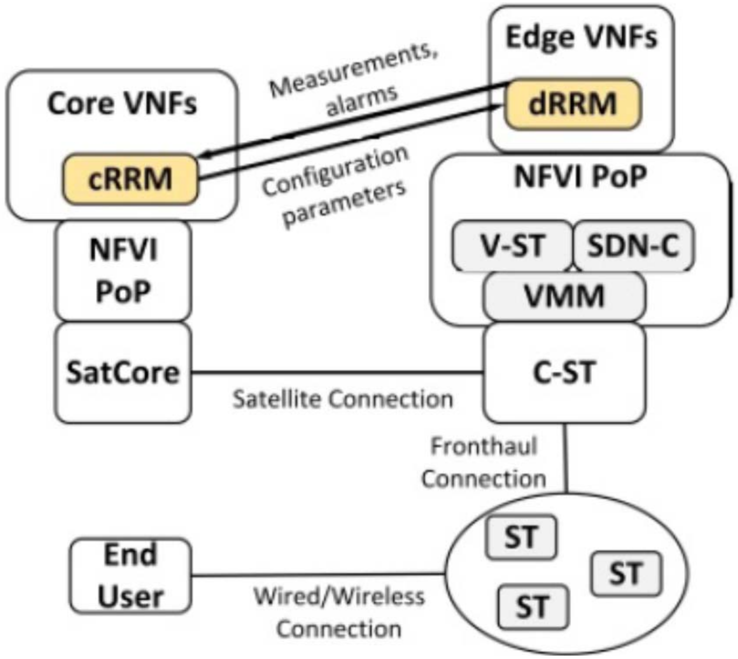
- Satellite access network. This consists of a cluster of SDN-enabled Hubs, connected to the satellite core network, and a distributed set of satellite terminals (STs), connected to the user equipment. Hubs and STs are interconnected via one or more channels (transponders) of a communication satellite. Both Hubs and STs are part of the NFVI. As shown in the Fig., some STs can be multi-tenant, whereas others can be dedicated to a single VSNO.
- A constellation of LEO satellites. Its purpose is to connect Hubs to STs.



Applicability of the models in future LEO SDN/NFV enabled satellite networks (5)

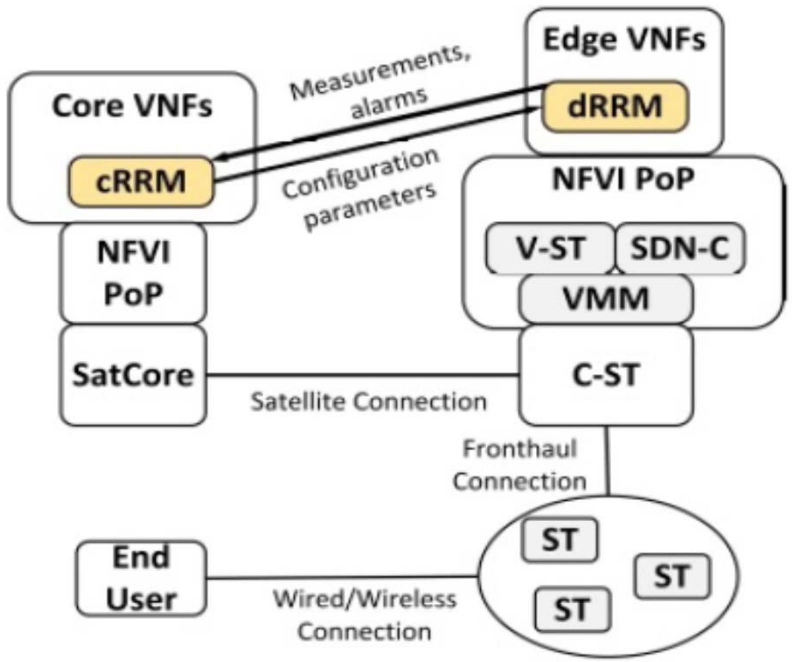
At the satellite core network (SatCore) level, the NFVI PoPs enable the execution of VNFs by the VSNOs. One such VNF could be a centralized radio resource management (cRRM) function that sets the appropriate configuration parameters to achieve, e.g., appropriate levels of QoS or CBP for VSNO's customers.

On the other hand, at the satellite access network level, there is a distributed set of STs, which form a centralized pool of ST resources (C-ST) that is owned and controlled by the SNO.



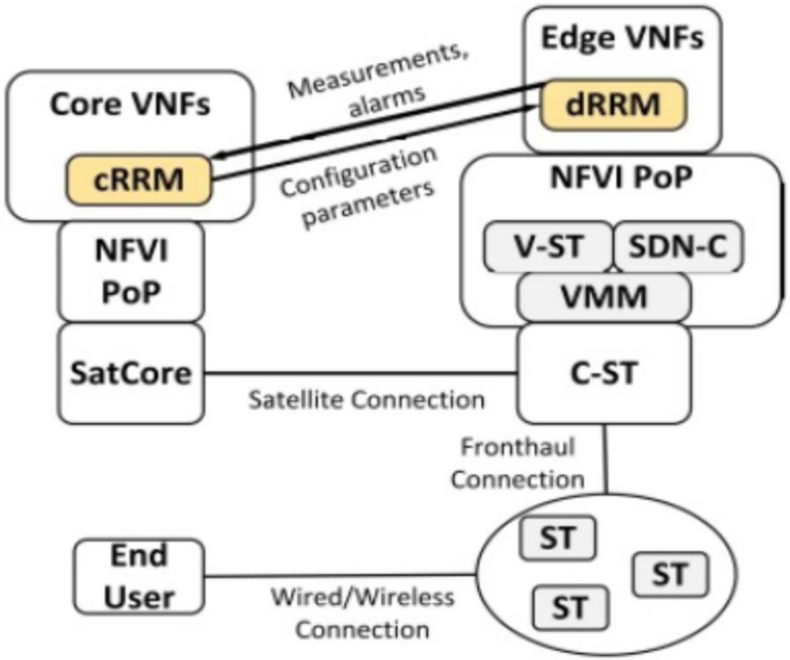
Applicability of the models in future LEO SDN/NFV enabled satellite networks (6)

To benefit from NFV, the C-ST functionality and services have been abstracted from the underlying infrastructure and virtualized (V-ST). To realize the virtualization, the virtual machine monitor (VMM) is used to manage the execution of V-STs. The NFVI PoP also includes a SDN controller that is responsible for routing decisions and for configuring the packet forwarding elements. On top of the NFVI, a VSNO can execute a number of edge VNFs, such as the distributed RRM (dRRM) function.



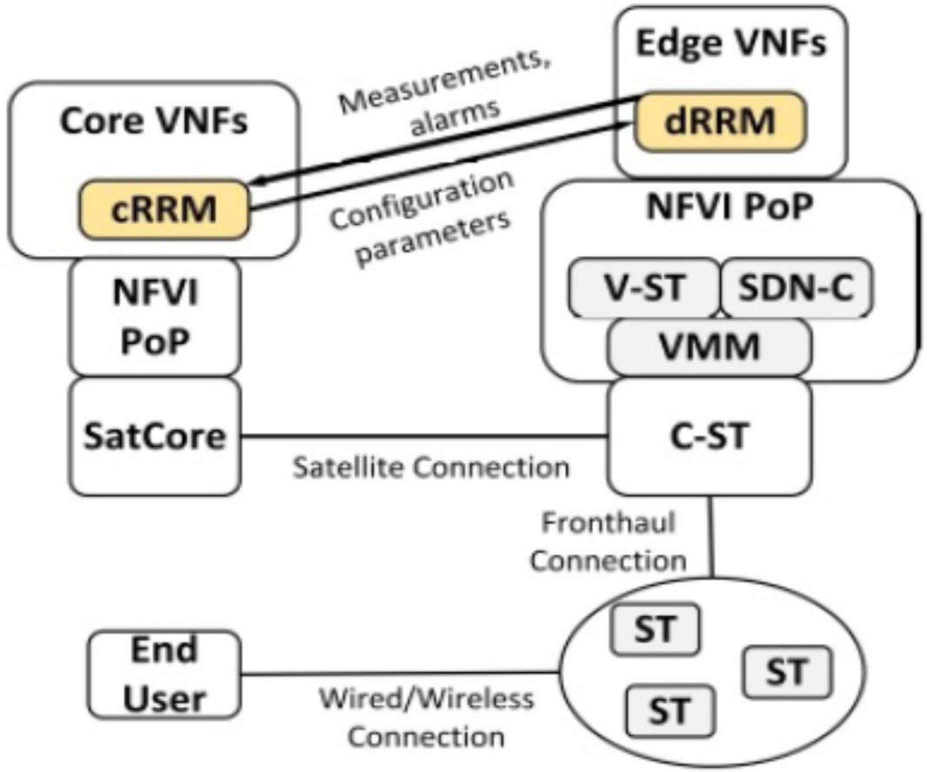
Applicability of the models in future LEO SDN/NFV enabled satellite networks (7)

The dRRM is logically connected to the cRRM. The cRRM sends to the dRRM various guidelines, configuration settings, and parameters. The cRRM determines the configuration parameters (e.g., CBP limits) based on a number of objectives (e.g., acceptable handover failure probabilities, coverage requirements, capacity requirements, etc). For example, the cRRM can select a set of TCA policy thresholds, N_k , or FCR policy channel reservation parameters, CR_k , that can ensure certain target CBP for a particular service-class.



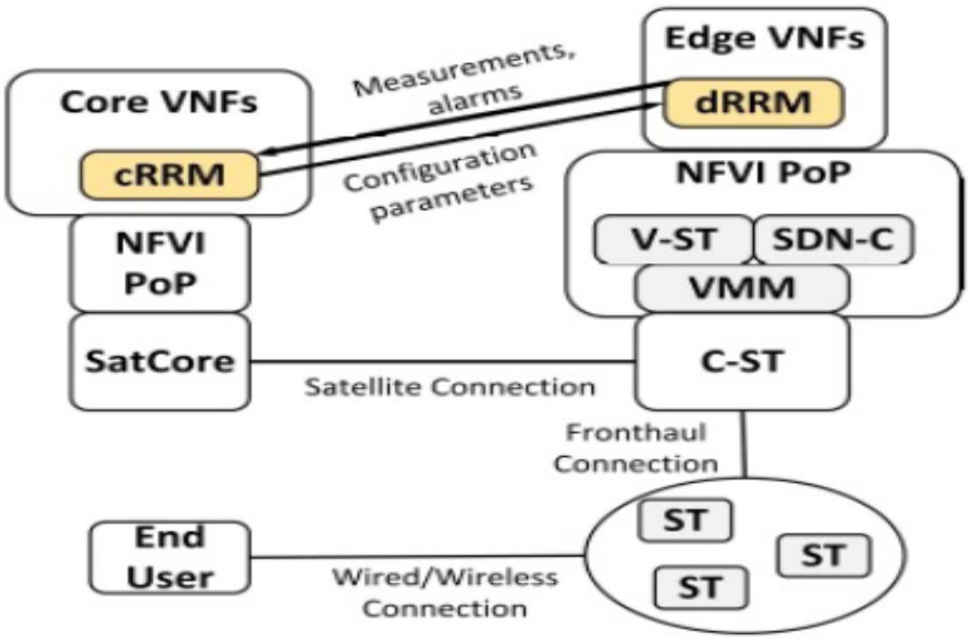
Applicability of the models in future LEO SDN/NFV enabled satellite networks (8)

The dRRM receives the configuration parameters (e.g., CBP limits) and acts accordingly (e.g., rejects connection requests that do not conform to the specified requirements). Also, the dRRM sends (at regular intervals or when a pre-defined condition is met) to the cRRM various performance measurements and alarms.



Applicability of the models in future LEO SDN/NFV enabled satellite networks (9)

E.g., the dRRM may be configured to report the handover failure probabilities per service to the cRRM. If the reported measurements violate the objectives/performance constraints (e.g., QoS is below a predefined level or the handover failure probability for a particular service is too high), the cRRM will re-calculate and send updated configuration parameters to the dRRM. For example, the dRRM may modify the CR_k parameters of the FCR policy, so that a different P_{fk} can be obtained for a particular service class *k*.



Possible future directions (1)

- Dynamic channel reservation policies (channels will be dynamically adjusted, based on e.g.: user location or the total QoS requirement of the system)
- Prioritization among service-classes or among users that belong to the same service-class (e.g. a military user may need a higher priority compared to an ordinary user)

For the single service-class case see:

J. Zhou, X. Ye, Y. Pan, F. Xiao, and L. Sun, “Dynamic channel reservation scheme based on priorities in LEO satellite systems”, Journal of Systems Engineering and Electronics, vol. 26, no. 1, pp. 1-9, February 2015.

X. Wang and X. Wang, “The research of channel reservation strategy in LEO satellite network”, Proc. 11th IEEE Int. Conf. Dependable, Autonomic and Secure Computing, Chengdu, China, Dec. 2013.

E. Papapetrou and F-N. Pavlidou, “Analytic study of Doppler-based handover management in LEO satellite systems”, *IEEE Trans. Aerospace and Electronics Systems*, vol. 51, issue 3, pp. 830-839, July 2005.

Possible future directions (2)

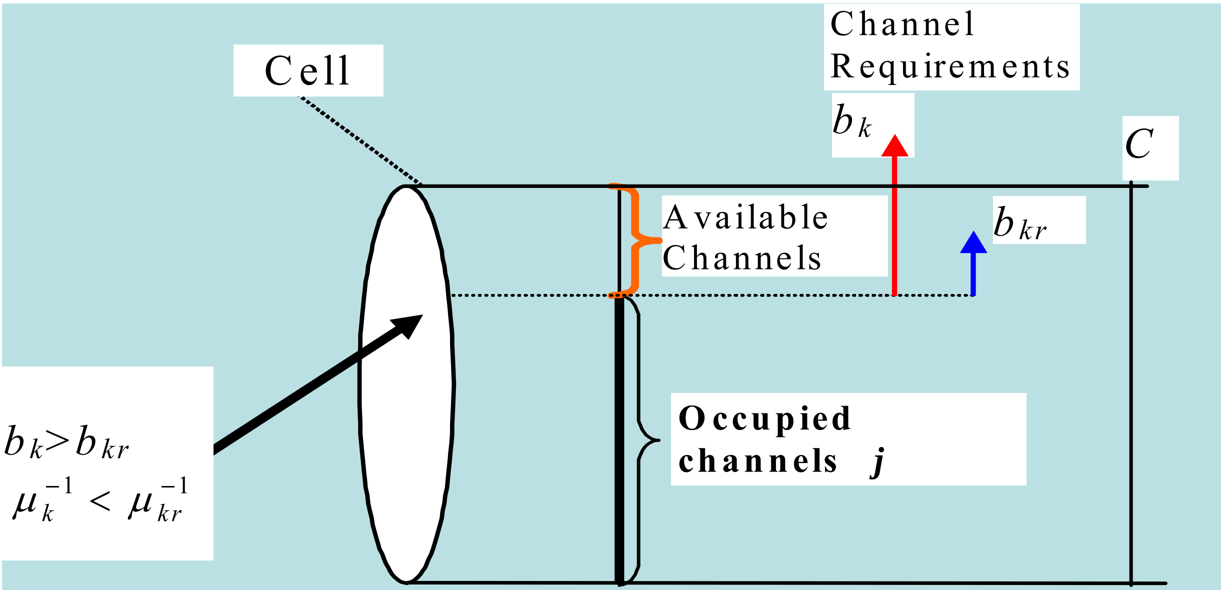
- ON-OFF traffic (calls alternate between periods of transmission and non-transmission) (not studied yet even in the single service case)

- Elastic traffic (the number of channels of an elastic call can vary between a min. and a max. value, while in-service). The acceptance of a new or handover call may require the channel compression of in-service calls. (not studied yet even in the single service case)

- Blocked calls retry to be connected with lower channel requirements (not studied yet even in the single service case)

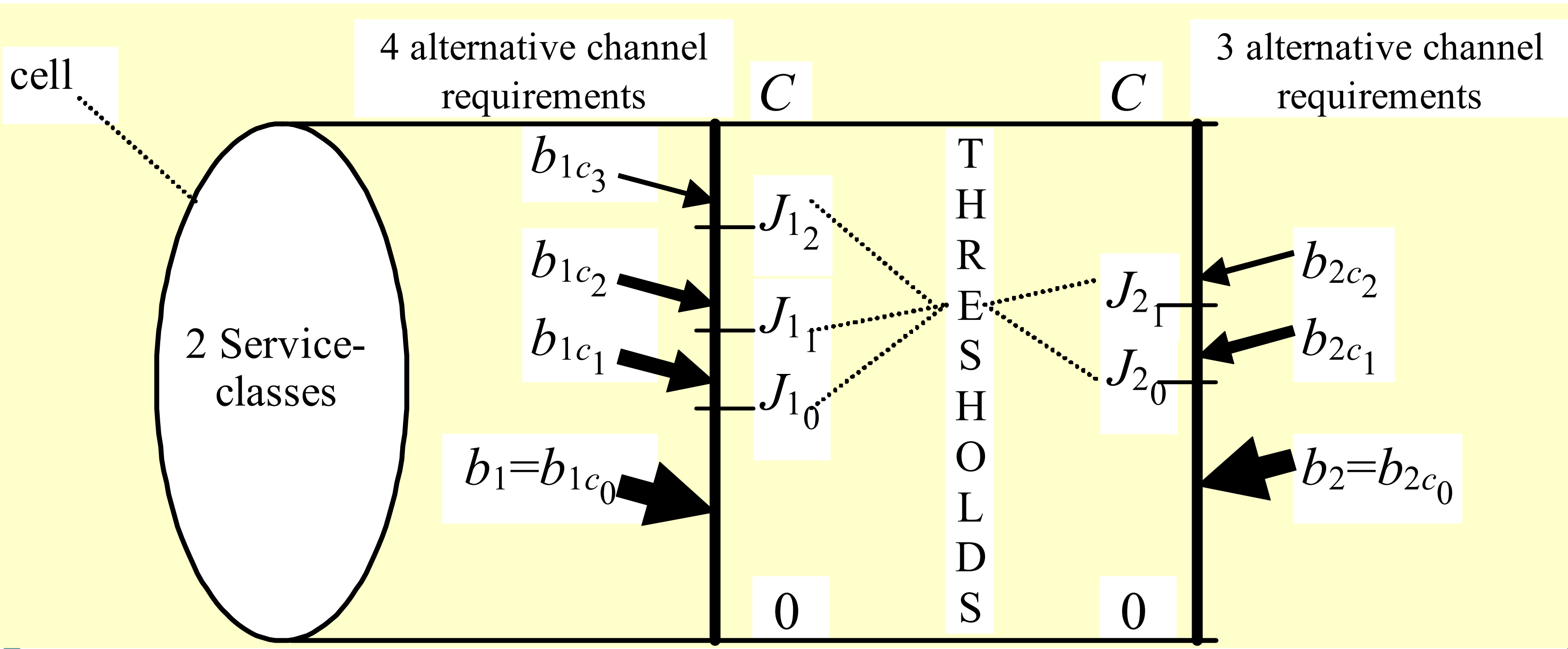
Possible future directions (3)

- Blocked calls retry to be connected with lower channel requirements (not studied yet even in the single service case)



Possible future directions (4)

- New calls of a service-class have different channel requirements when entering the source cell. Depending on the number of occupied channels they enter with a certain channel requirement (not studied yet even in the single service case)



Possible future directions (5)

- Include in the Call Admission Control the case of rain fading
  - under rain conditions, additional channels are required to dynamically mitigate rain fading (*The idea is to estimate an additional capacity that should be allocated to each connection to carry redundant forward error correction (FEC) bits during rain events*.) (no recursive formulas proposed in the literature even for the single service-class case)

D. K. Petraki, M. P. Anastasopoulos, and P. G. Cottis, “Call admission control in satellite networks under rain fading,” IEEE Communications Letters,, vol. 12, no. 5, pp. 377–379, 2008.

M. P. Anastasopoulos, D. K. Petraki, A. V. Vasilakos, P. G. Cottis, and H.-H. Chen, “Call admission control scheme for multiclass services under rain fading for satellite networks,” IEEE Transactions on Wireless Communications, vol. 8, no. 5, pp. 2473–2483, 2009.

O. Imole, T. Walingo, and F. Takawira, “Call admission control for multimedia connections in interactive satellite networks”, Proc. IEEE AFRICON, 2015.

O. Imole and T. Walingo, “Call admission control for rain-impacted multimedia satellite networks”, Proc. IEEE AFRICON 2017.

Thank You !