On Look-Ahead Strategy for Movement-Based Location Update. A General Formulation

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A presentation in honor of
Dr. Gunter Haring,
promoted to the figure of Professor Emeritus in University of Vienna

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Outlines

1. Mobility management
2. Location management
3. Global versus local location update strategies
4. Look-Ahead movement-based procedure
5. Terminal paging procedure
6. Mobility models used in the evaluation procedures
7. Scenario under study and numerical results
8. Conclusions

Overview on Mobility management

- Mobility management is composed of two components:
  - Location Management
  - Handoff Management

- **Location Management** for tracking the location of mobile users in order to be reachable anywhere anytime.

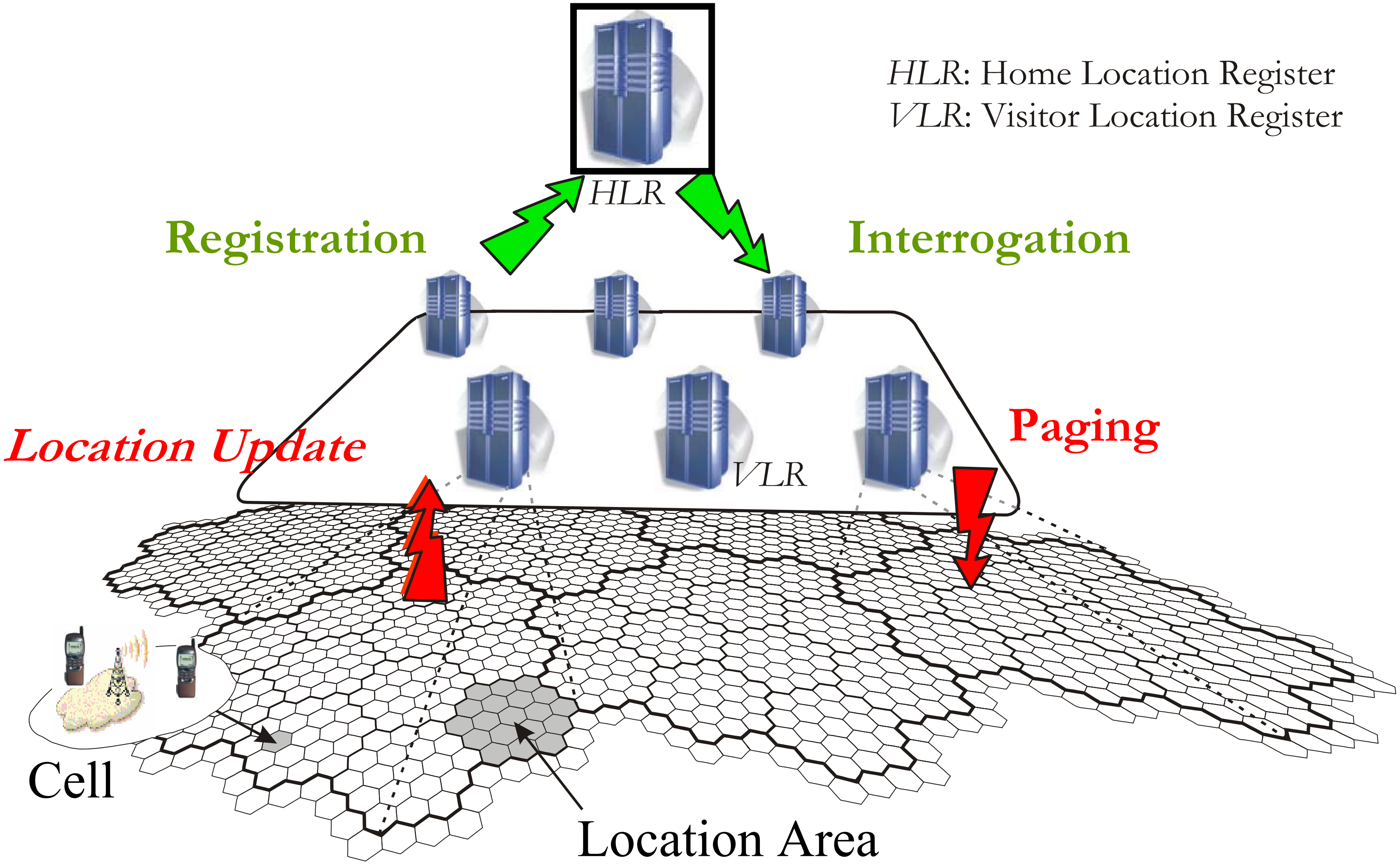
- **Handoff Management** for maintaining sessions between mobile users while they change their attachment points to the system's infrastructure.

Location management procedures –i-

- Location management: set of procedures that allow an MT being reachable at any time

- Location Management
  - Location Update (LU)
    - Location Update (LU) (CAI)
    - Registration (RG) (FN)
  - Call Delivery (CD)
    - Interrogation (IG) (FN)
    - Terminal Paging (PG) (CAI)

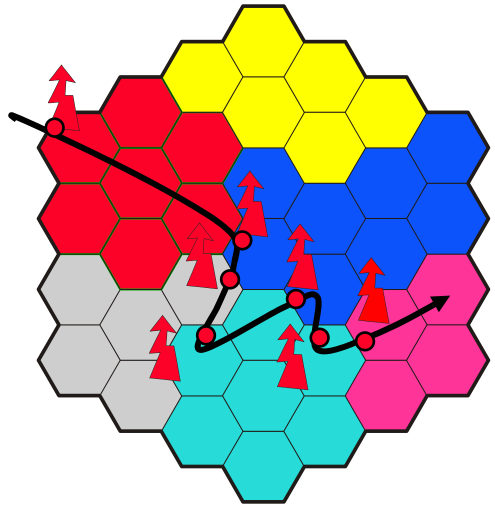
Location management procedures –ii-



Classification of Location update procedures

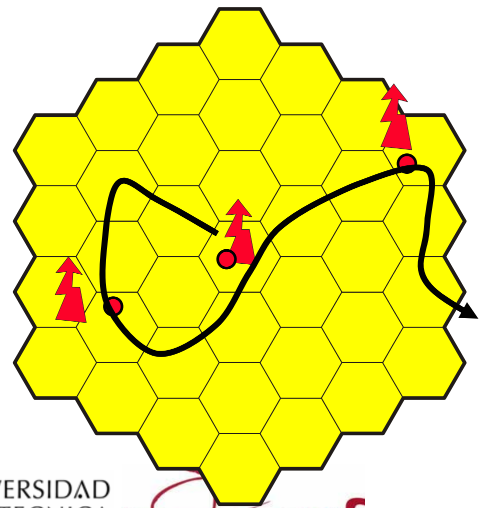
- **Classification of *LU* procedures**
  - ⇨ Static:
    - Location Area (*LA*)
  - ⇨ Dynamic:
    1) Time,
    2) **Movement,**
    3) Distance

Static strategies:

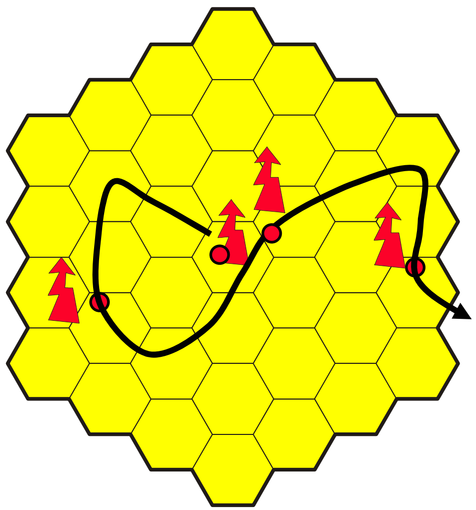


Dynamic strategies:

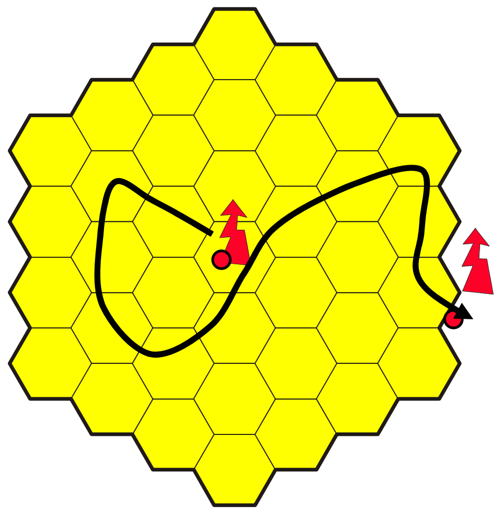
Time



Movement, M=4

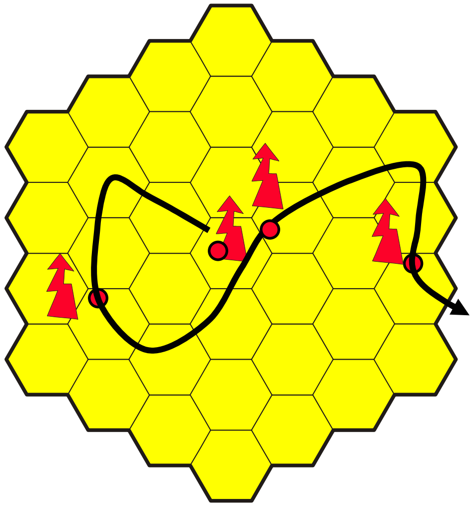


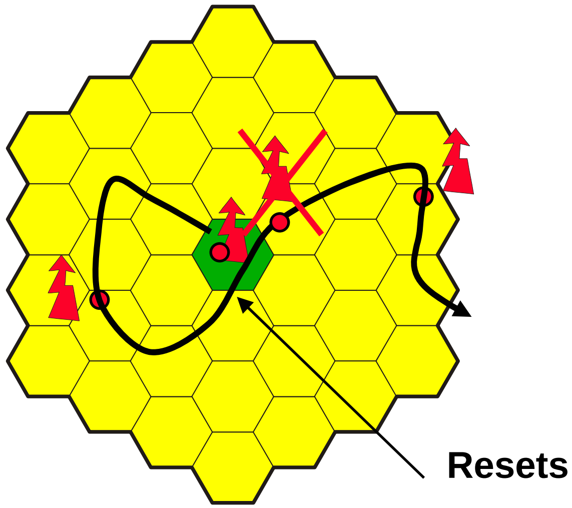
Distance, D=4



Location management under study

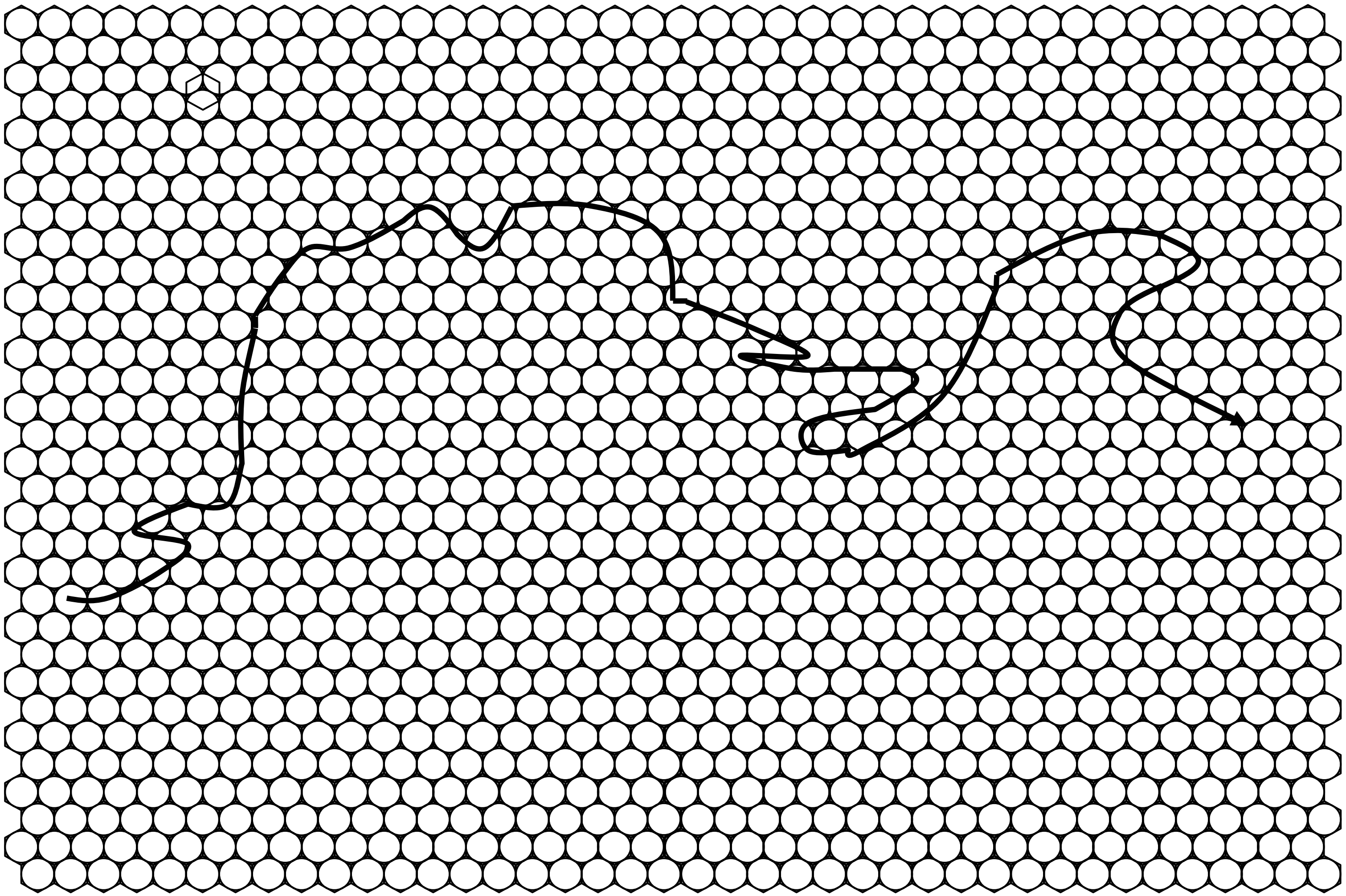
- General framework of the movement-based LU scheme: each time the MT revisits the cell it had contact with the fixed network, with $p + q + r = 1$:
  - Increases the movement-counter with probability p
  - Freezes (stops) the movement-counter with probability q
  - **Resets the movement-counter with probability *r***



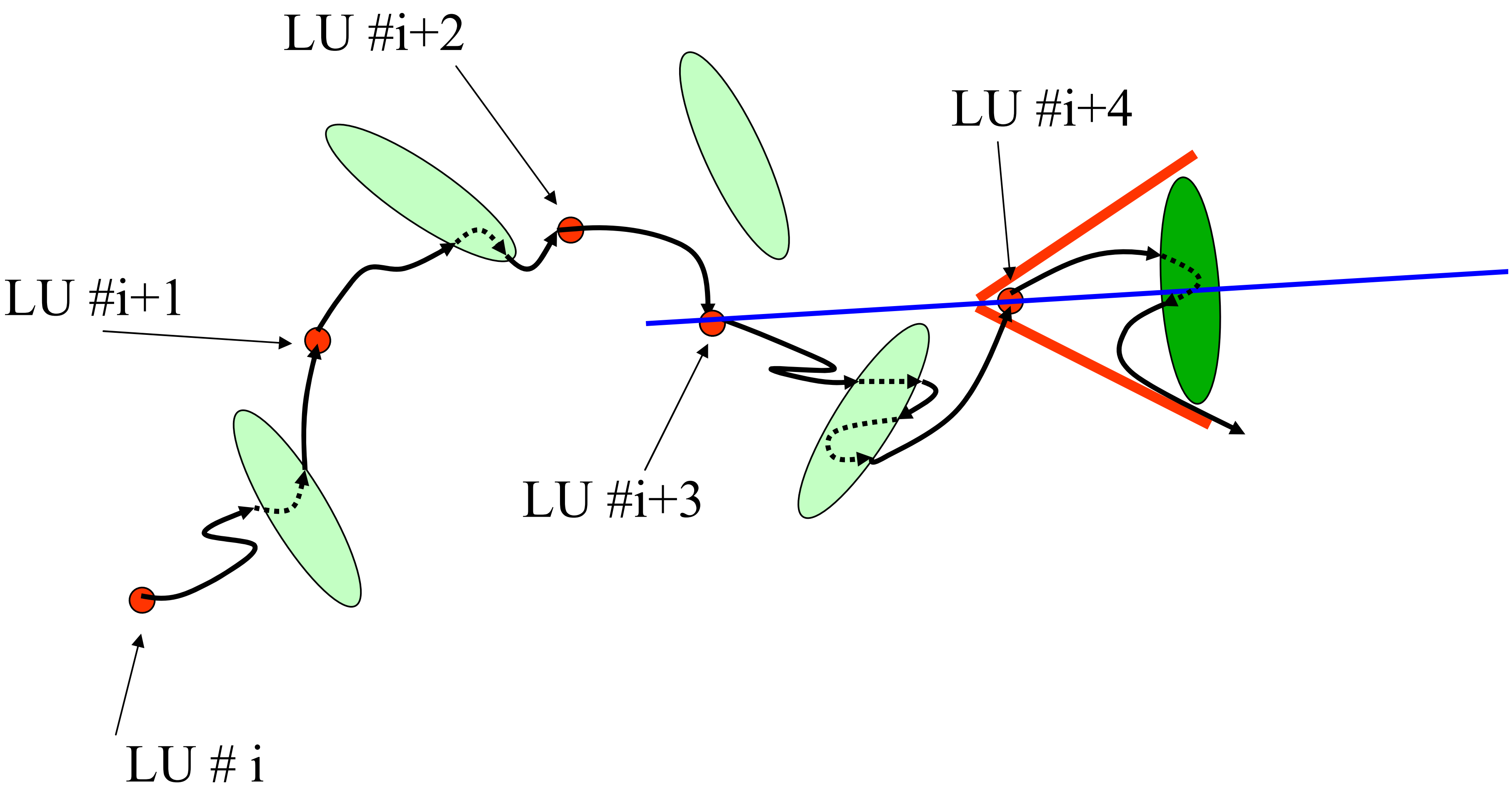


M=4, with **r=1**

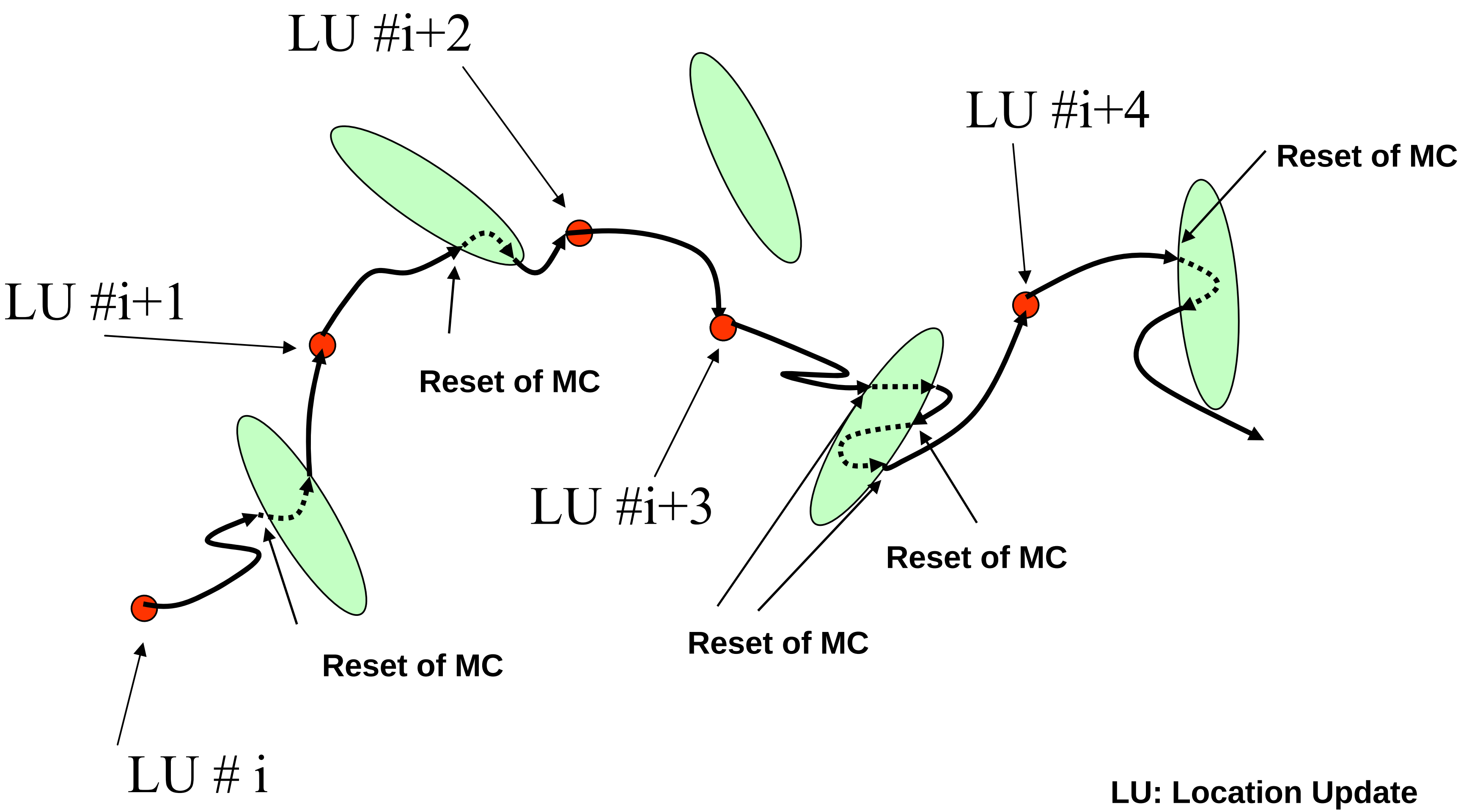
Trajectory of a Mobile Terminal



Look-Ahead movement-based -xiv-



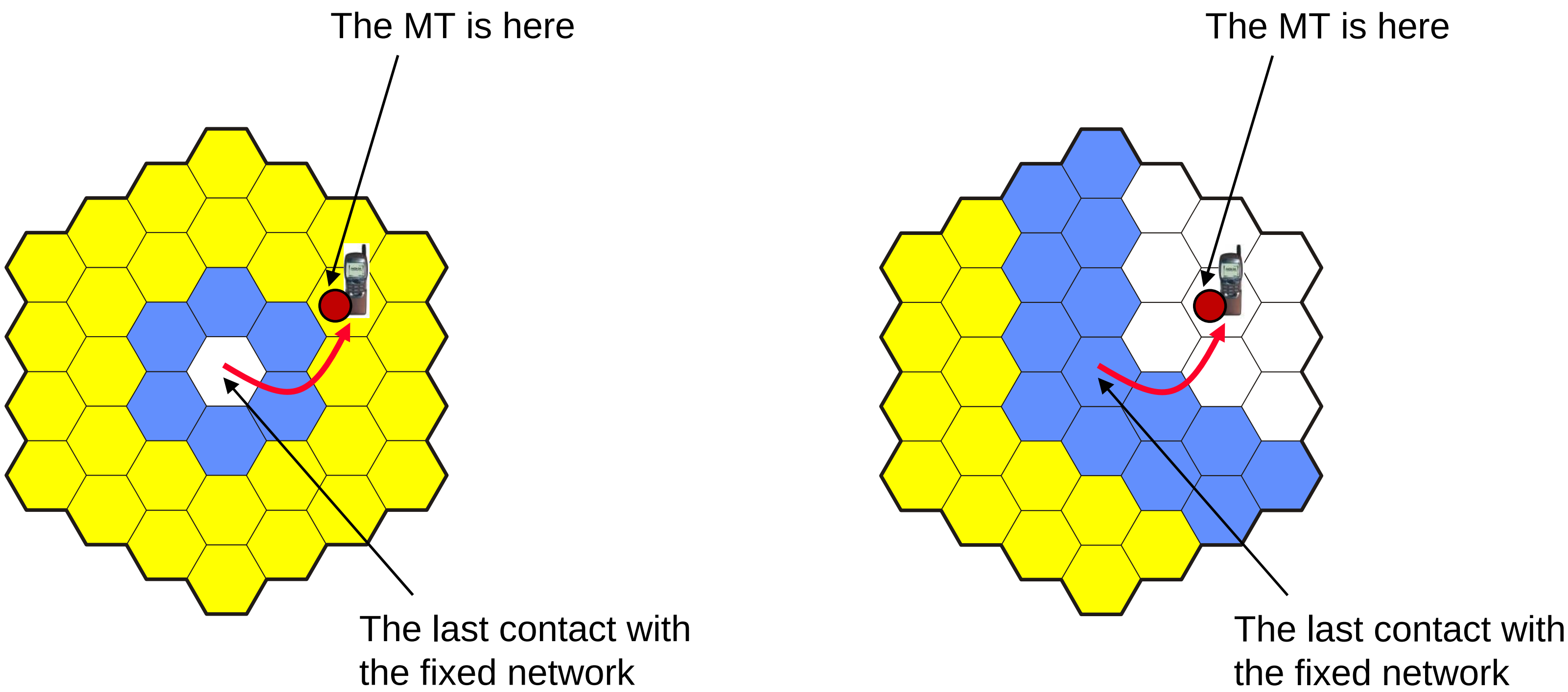
Look-Ahead movement-based -xv-



LU: Location Update
MC: Movement Counter

Terminal paging procedure -i-

- The Registration Area (RA) is divided into l Paging Areas (PA)
  - Shortest-distance-first (SDF) Paging: The MT is found at shot # 3.
  - SDF Paging strategy is not the best for mobility with high directionality



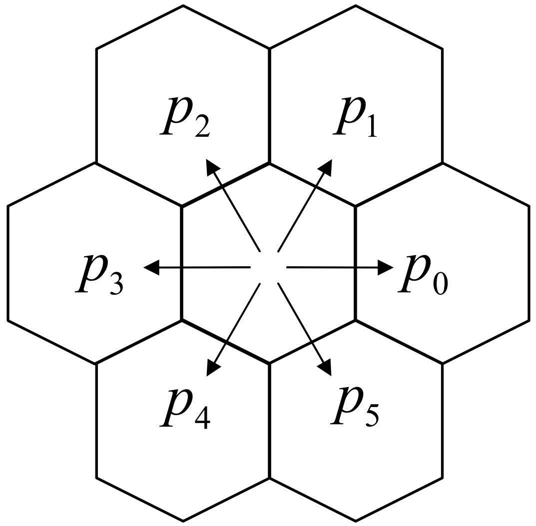
SDF Paging: The MT is found at shot # 3

No SDF Paging: The MT is found at shot # 1

Scenarios and mobility models -i-

- Mobility models
  - Location management depends on mobility patterns of Mobile Terminals (MTs)
  - Random walk mobility model commonly used
- We propose
  - A versatile 2-D mobility model that takes into account the directionality of the MT.
- We provide
  - An analytical framework to evaluate the LOOK-AHEAD movement-based combined with a selective paging strategy.

Scenario -i-



$$p_0 = P_0(\beta) = \frac{\beta^3}{D(\beta)}$$

$$p_1 = P_1(\beta) = p_5 = P_5(\beta) = \frac{\beta^2}{D(\beta)}$$

$$p_2 = P_2(\beta) = p_4 = P_4(\beta) = \frac{\beta}{D(\beta)}$$

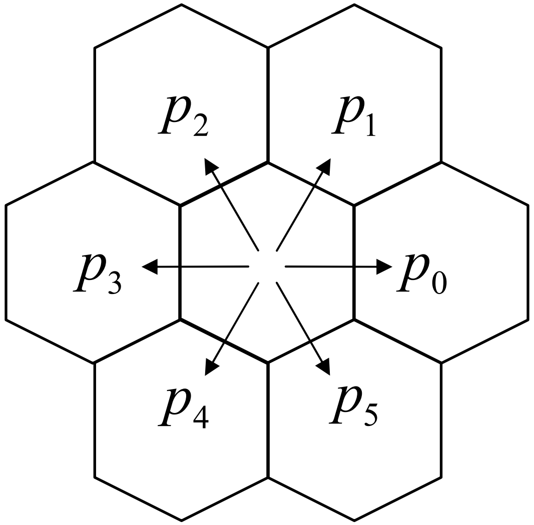
$$p_3 = P_3(\beta) = \frac{1}{D(\beta)}$$

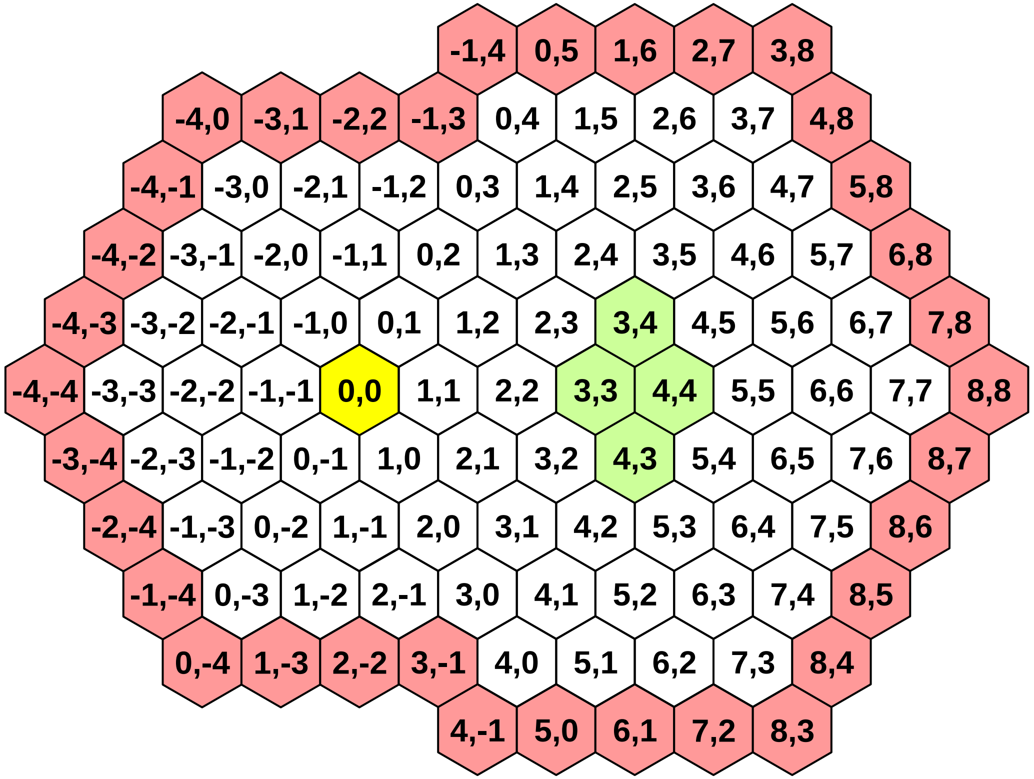
$$D(\beta) = \beta^3 + 2\beta^2 + 2\beta \ \ +1$$

Random walk, when $\beta = 1$

Straight ahead trajectory when $\beta \to \infty$

Scenario -ii-





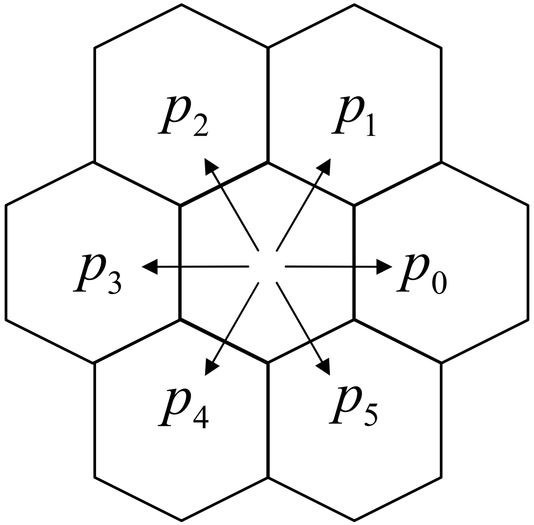
Starting point

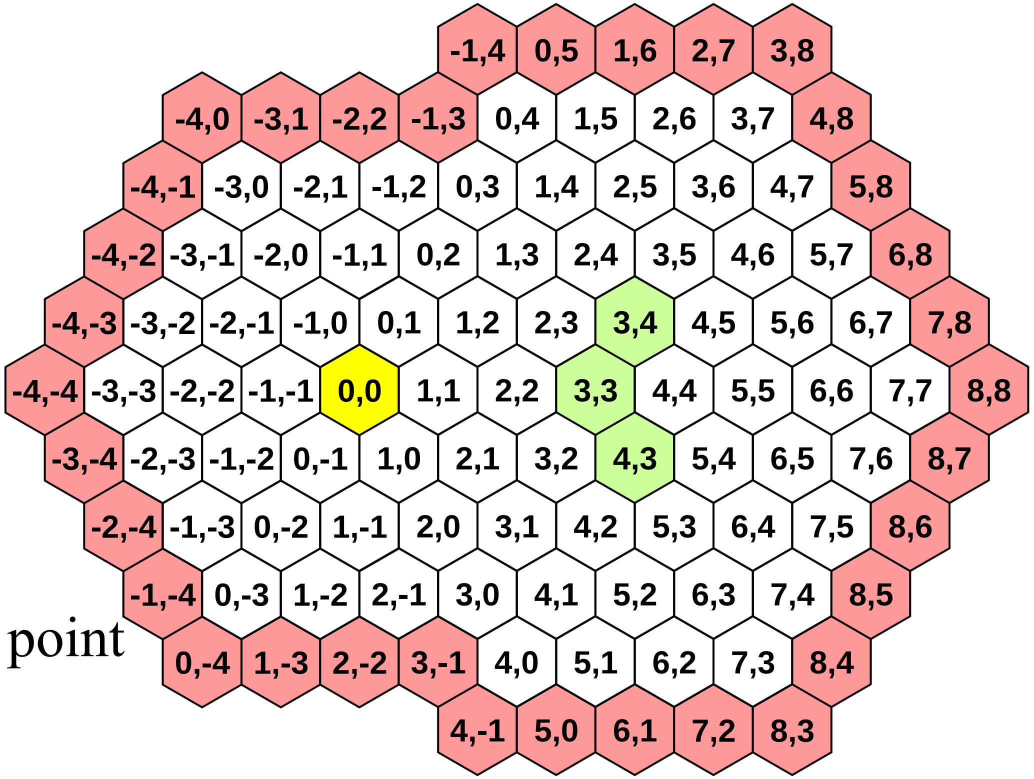
Absorbing states

External ring to the paging area

Movement counter, *M* =4

Scenario -iii-





Set $0 = \{0 = (0,0)\}$, the starting point

Set $\Delta = \{j = (3,3), k = (3,4), l = (4,3)\}$, the absorbing states

$$P_{\mathrm{nab}\,(0,\,\Delta)}(M) = 1 - \sum_{n=1}^{M} f_{0,\Delta}^{(n)} = 1 - \sum_{n=1}^{M} \left({}_{\bar{\Delta}_j}f_{0,j}^{(n)} + {}_{\bar{\Delta}_k}f_{0,k}^{(n)} + {}_{\bar{\Delta}_l}f_{0,l}^{(n)} \right);\ \overline{\Delta}_{\mathrm{j}} = \{\mathrm{k},\mathrm{l}\};\ \overline{\Delta}_{\mathrm{k}} = \{\mathrm{j},\mathrm{l}\};\ldots.$$

$$P_{\mathrm{nab}\,(\mathrm{s},\,\Delta)}(M) = 1 - \sum_{n=1}^{M} f_{s,\Delta}^{(n)} = 1 - \sum_{n=1}^{M} \left({}_{\bar{\Delta}_j}f_{s,j}^{(n)} + {}_{\bar{\Delta}_k}f_{s,k}^{(n)} + {}_{\bar{\Delta}_l}f_{s,l}^{(n)} \right) \text{ for } s = j, k, l$$

Performances on location update -i-

- On the number of Location Updates in *m* movements

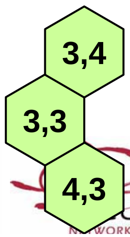
$$P_{\mathrm{nab}\,(0,\,\Delta)}(M)=1-\sum_{n=1}^{M} f_{0,\Delta}^{(n)}=1-\sum_{n=1}^{M}\left({}_{\bar{\Delta}j}f_{0,j}^{(n)}+{}_{\bar{\Delta}k}f_{0,k}^{(n)}+{}_{\bar{\Delta}l}f_{0,l}^{(n)}\right)=1-\sum_{n=1}^{M}\mathbf{f}_{0,\Delta}^{(n)}\mathbf{1}$$

$$P_{\mathrm{nab}\,(s,\,\Delta)}(M)=1-\sum_{n=1}^{M} f_{s,\Delta}^{(n)}=1-\sum_{n=1}^{M}\left({}_{\bar{\Delta}j}f_{s,j}^{(n)}+{}_{\bar{\Delta}k}f_{s,k}^{(n)}+{}_{\bar{\Delta}l}f_{s,l}^{(n)}\right)\ \text{for}\ s=j,k,l$$

$$M_0^{(m)}=\sum_{k=0}^{\infty}kP_0^{(m)}(k)=\begin{cases}0; & \text{for } m<M\\ \sum_{n=1}^{M}\mathbf{f}_{0,\Delta}^{(n)}\mathbf{M}_{\Delta}^{(m-n)}+P_{\mathrm{nab}\,(0,\,\Delta)}(M)[1+M_0^{(m-M)}]; & \text{for } m\ge M\end{cases}$$

$$\mathbf{M}_{\Delta}^{(m)}=\sum_{k=0}^{\infty}k\,\mathbf{P}_{\Delta}^{(m)}(k)=\begin{cases}0; & \text{for } m<M\\ \sum_{n=1}^{M}\mathbf{f}_{\Delta,\Delta}^{(n)}\mathbf{M}_{\Delta}^{(m-n)}+\mathbf{P}_{\mathrm{nab}\,(\Delta,\,\Delta)}(M)[1+M_0^{(m-M)}]; & \text{for } m\ge M\end{cases}$$

$\text{Set } 0=\{0=(0,0)\},$ the starting point



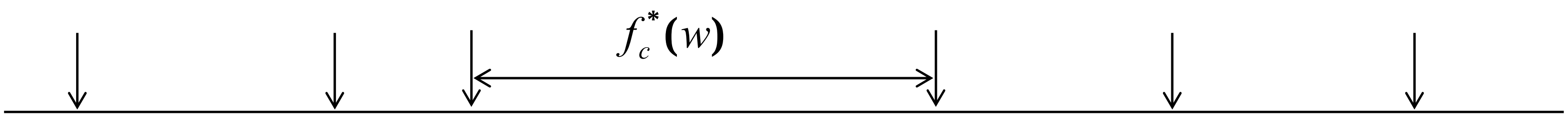
$\text{Set } \Delta=\{j=(3,3),\,k=(3,4),\,l=(4,3)\}$, the absorbing states

Performances on location update -ii-

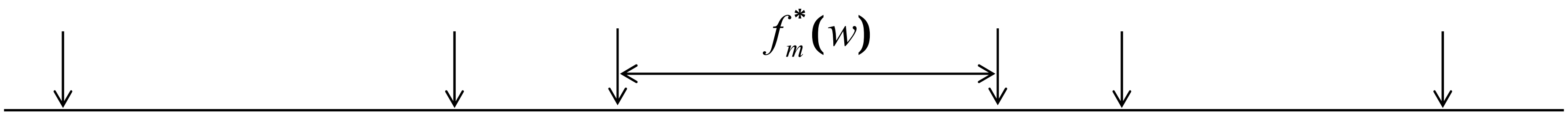
- On the *mean* number of Location Updates between two consecutive call arrivals.

$$\overline{\#_{LU}} = \sum_{m=M}^{\infty} M_0^{(m)} \alpha(m)$$

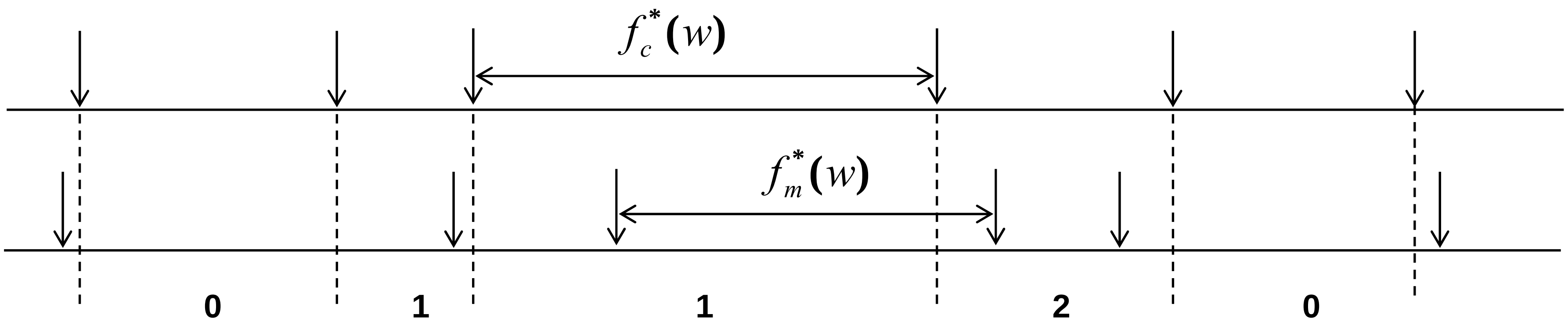
$f_c^*(w)$ The LT of the inter-arrival call distribution



$f_m^*(w)$ The LT of the residence time distribution in a cell



- $\alpha(m)$, the probability of *m* movements between two consecutive call arrivals.



$$\alpha(m)=\begin{cases}\dfrac{1}{2\pi i}\displaystyle\int_{c-i\infty}^{c+i\infty}\dfrac{[1-f_{mr}^*(w)]}{w}f_c^*(-w)\mathrm{d}w;\ \text{for } m=0\\[2ex]\dfrac{1}{2\pi i}\displaystyle\int_{c-i\infty}^{c+i\infty}\dfrac{f_{mr}^*(w)[1-f_m^*(w)]f_m^*(w)^{m-1}}{w}f_c^*(-w)\mathrm{d}w;\ \text{for } m>0\end{cases}$$

$$f_{mr}^*(w)=\frac{\lambda_m}{w}[1-f_m^*(w)]$$

Residual life time

Performances on location update -iv-

- On the *mean* number of Location Updates between two consecutive call arrivals.

$$\overline{\#_{LU}} = \sum_{m=M}^{\infty} M_0^{(m)} \alpha(m)$$

$$\begin{aligned}
\overline{\#_{LU}} &= \sum_{m=M}^{\infty} M_0^{(m)} \alpha(m) = \\
&= \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} \frac{f_{mr}^{*}(w)[1 - f_m^{*}(w)]}{w f_m^{*}(w)} M_0^{*}(f_m^{*}(w)) f_c^{*}(-w) \mathrm{d}w = \\
&= -\sum_{p \in \sigma_c} \mathrm{Res}_{\mathrm{w=p}} \frac{f_{mr}^{*}(w)[1 - f_m^{*}(w)]}{w f_m^{*}(w)} M_0^{*}(f_m^{*}(w)) f_c^{*}(-w)
\end{aligned}$$

Cauchy‘s Residue Theorem

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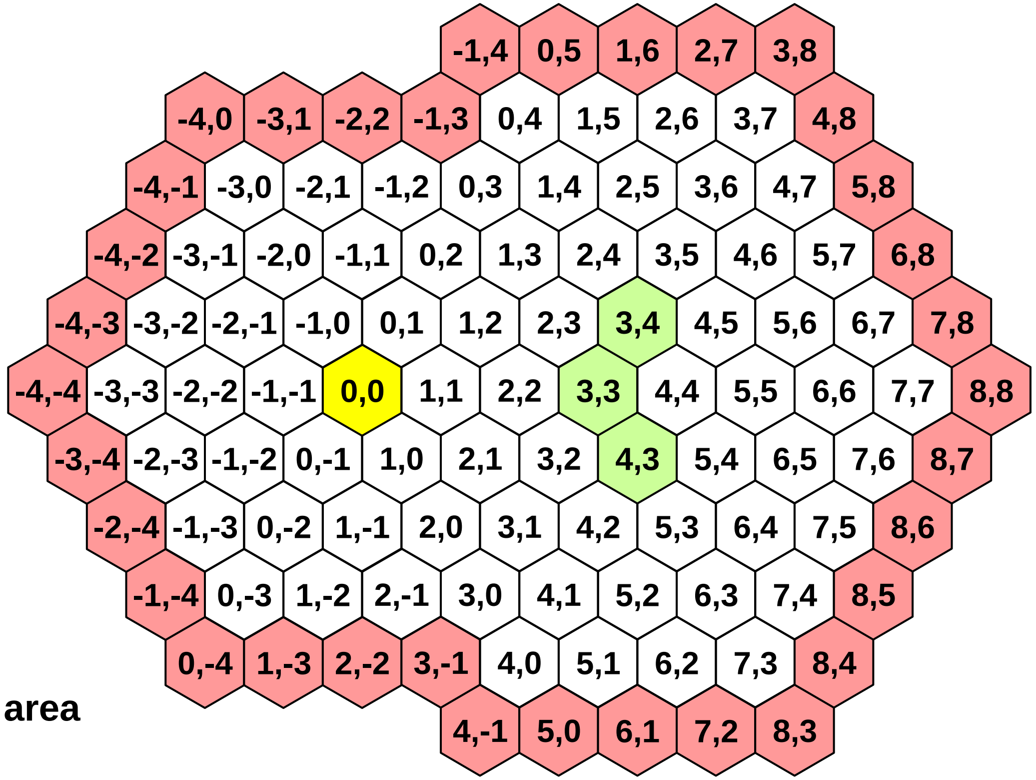
Paging procedure -i-

- Paging procedure. Blanket paging: single step

The whole set of cells are paged simultaneously



Starting point

Absorbing states

External ring to the paging area

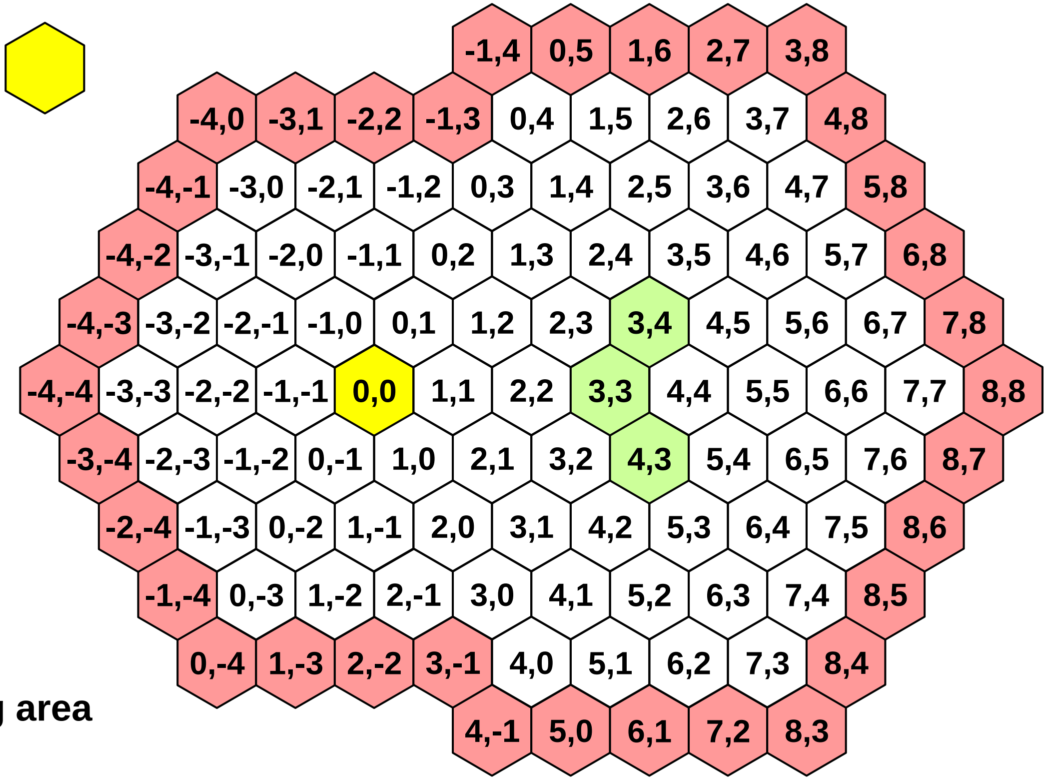
Movement counter, *M* =4

Paging procedure -ii-

- Paging procedure. Selective: two steps

First set of cells to be paged:
Set A= (3,3), (3,4), (4,3), (4,4)

Second set of cells to be paged:
Set U-A



Starting point

Absorbing states

External ring to the paging area

Movement counter, *M* =4

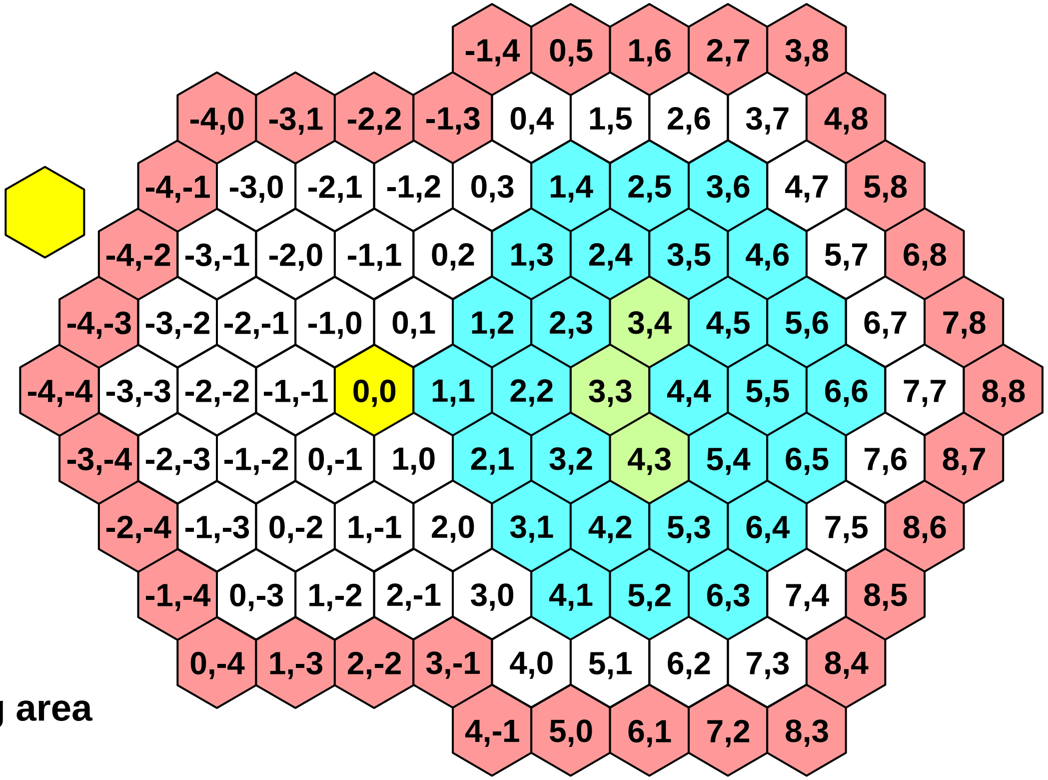
Paging procedure -iii-

- Paging procedure. Selective: two steps

First set of cells to be paged:
Set A= (3,3), (3,4), (4,3), (4,4)

Second set of cells to be paged:
Set B=

Third set of cells to be paged:
Set U-A-B



Starting point

Absorbing states

External ring to the paging area

Movement counter, *M* =4

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Some examples

•Cell residence time

Gamma distribution

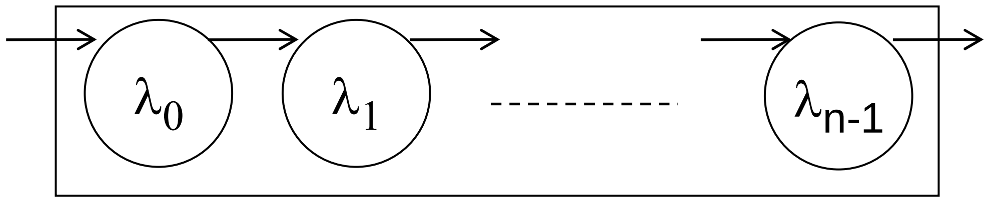
$$f_m(t) = \frac{(\gamma\lambda_m)^{\gamma} t^{\lambda-1}}{\Gamma(\gamma)} e^{-\gamma\lambda_m t}; \quad f_m^*(w) = \left(\frac{\gamma\lambda_m}{w+\gamma\lambda_m}\right)^{\gamma}; \quad C_m^2 = \frac{1}{\gamma}$$

(Squared coefficient of variation)

•Inter arrival call distribution

Erlangian-type distribution (no multiple roots)

$$f_{c,e}^*(w) = \prod_{i=0}^{n-1} \frac{\lambda_i}{w+\lambda_i}; \qquad \lambda_i = \frac{\lambda_c}{a^i}\frac{1-a^n}{1-a}$$



$$C_{c,e}^2 = \frac{\sigma_e^2}{m_e^2} = \frac{(1+a^n)(1-a)}{(1-a^n)(1+a)} \le 1$$

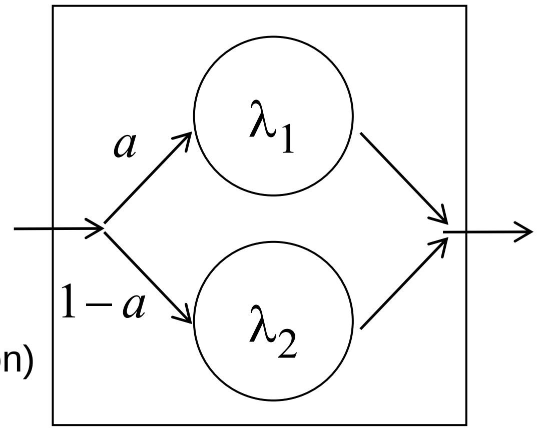
(Squared coefficient of variation)

Hyper exponential distribution H2

$$f_{c,h}^*(w) = a\frac{\lambda_1}{w+\lambda_1} + (1-a)\frac{\lambda_2}{w+\lambda_2}; \quad \lambda_2 = n\lambda_1; \quad \frac{1}{\lambda_c} = \frac{a}{\lambda_1} + \frac{1-a}{n\lambda_1}$$

$$C_{c,h}^2 = \frac{\sigma_h^2}{m_h^2} = \frac{1+2an(n-1)-a^2(n-1)^2}{1+2a(n-1)+a^2(n-1)^2} \ge 1$$

(Squared coefficient of variation)



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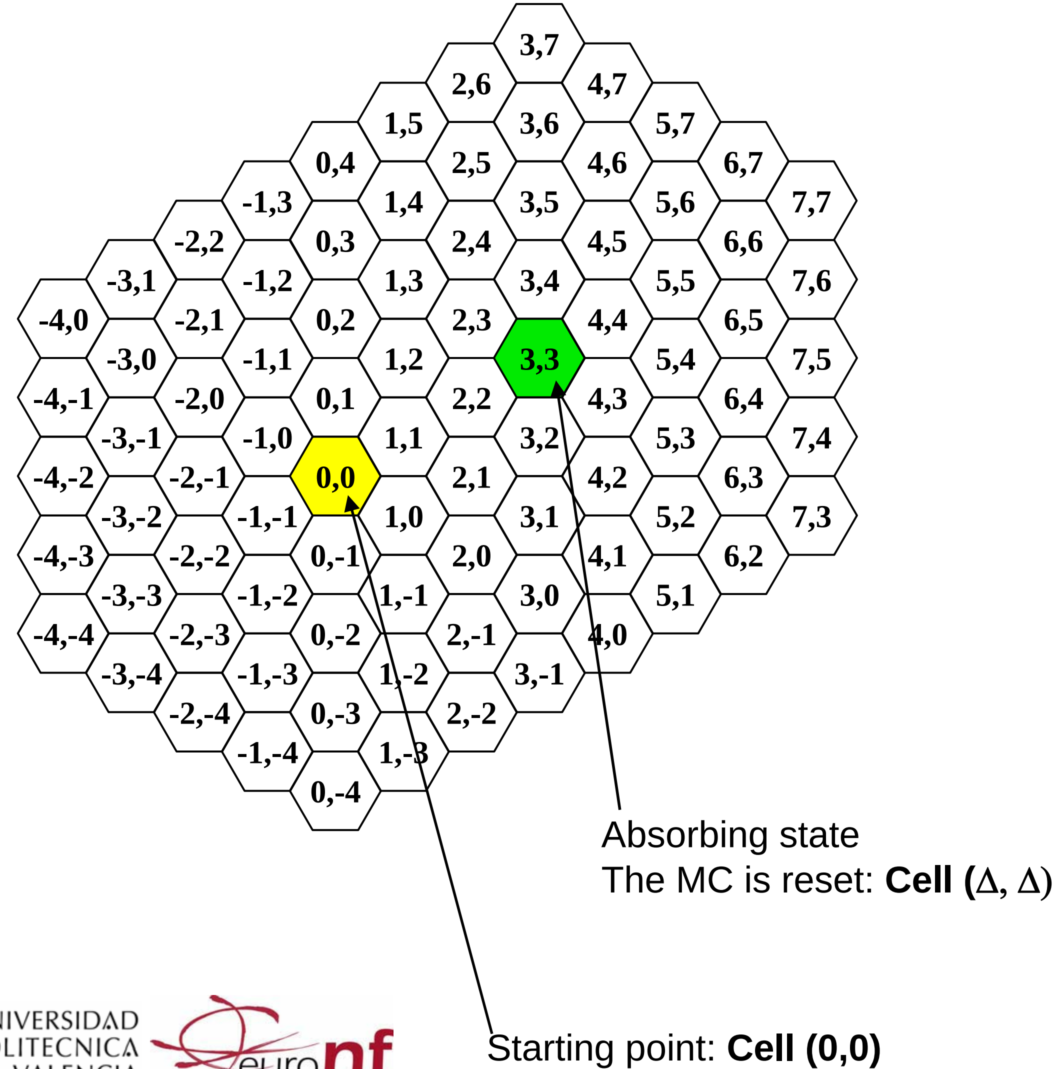
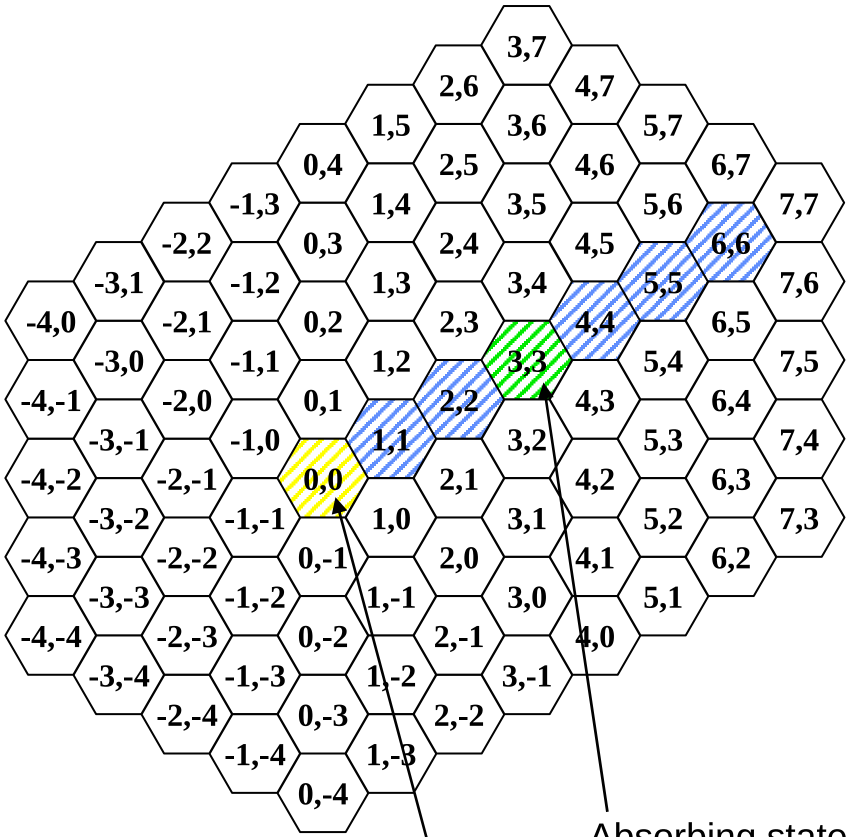
Scenario in the examples

- A single absorbing state (Δ,Δ)=(3,3)
- Movement counter M=5

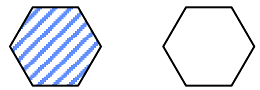


Paging procedure -i-

- Paging procedure. Single steps



The whole set of 88 cells are paged simultaneously

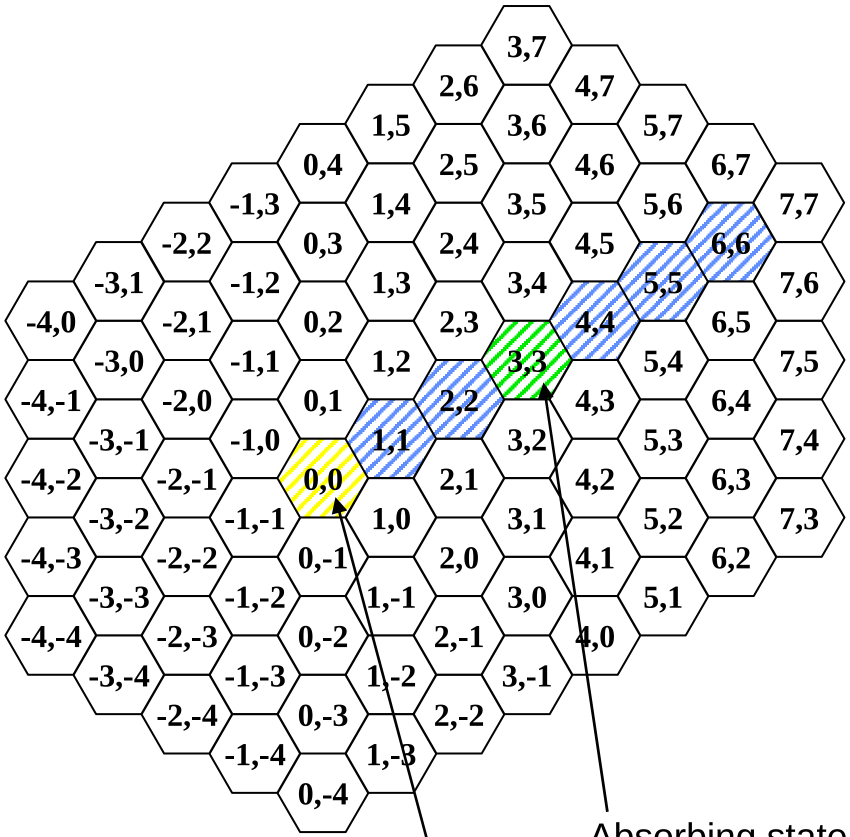


Absorbing state
The MC is reset: **Cell (Δ, Δ)**

Starting point: **Cell (0,0)**

Paging procedure -ii-

- Paging procedure. Selective: Two steps



First set of 7 cells to be paged:
Set A= (0,0), (1,1), (2,2), (3,3), (4,4), (5,5), (6,6)

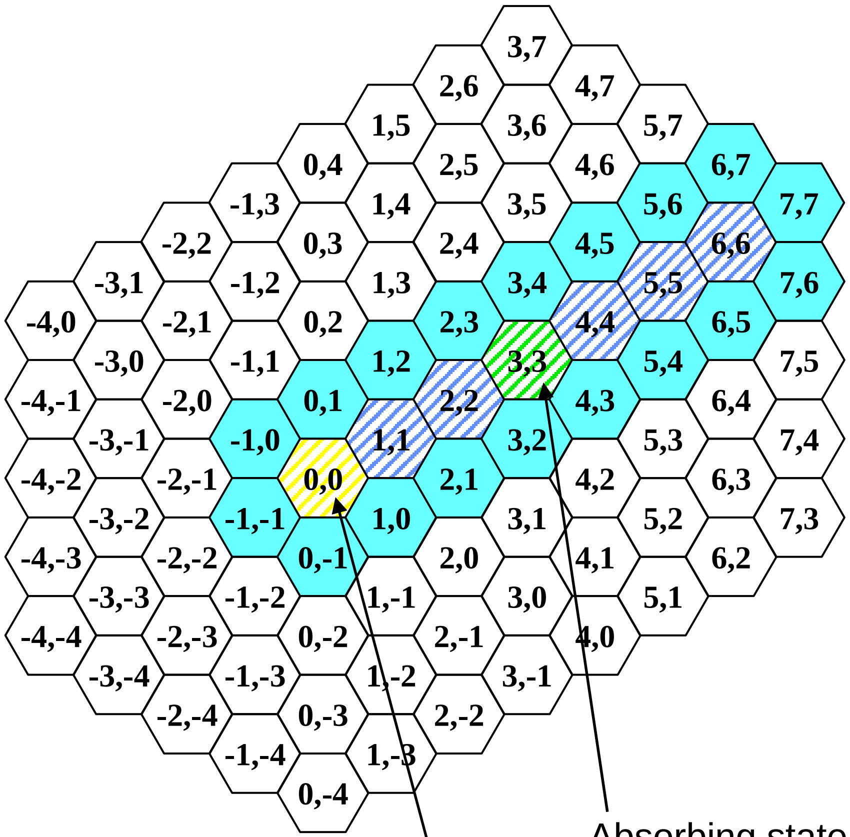
Second set of 81 cells to be paged:
Set U-A

Absorbing state
The MC is reset: **Cell** (Δ, Δ)

Starting point: **Cell (0,0)**

Paging procedure -iii-

- Paging procedure. Selective: three steps



First set of 7 cells to be paged:
Set A= (0,0), (1,1), (2,2), (3,3), (4,4), (5,5), (6,6)

Second set of 18 cells to be paged:
Set B= First ring of cells around set A

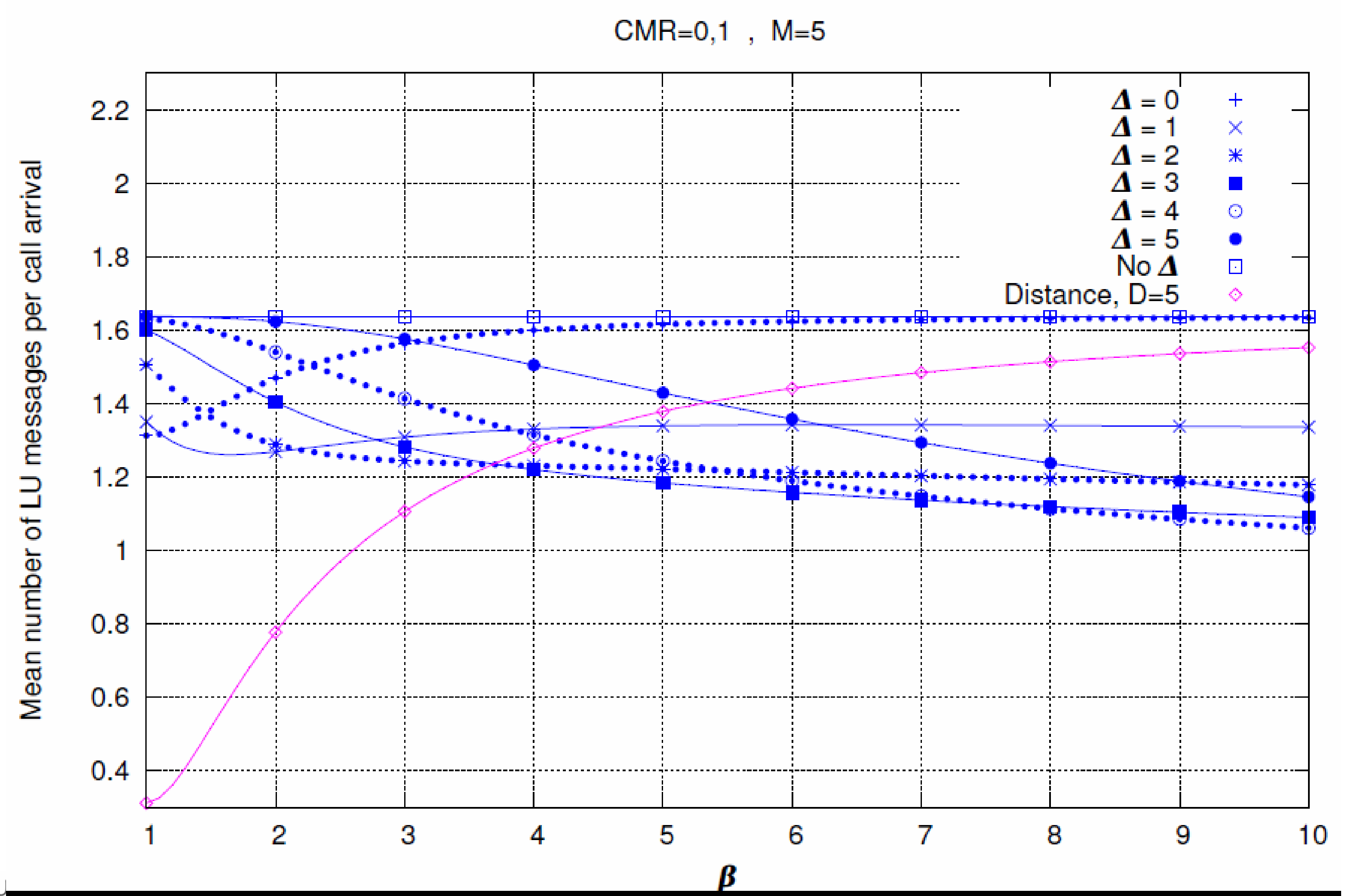
Third set of 63 cells to be paged:
Set C= U-A-B

Absorbing state
The MC is reset: **Cell (Δ, Δ)**

Starting point: **Cell (0,0)**

LU: Comparison with *Distance-Based*

$$f_c(t) = \lambda_c e^{-\gamma\lambda_c t}; \quad f_c^*(w) = \frac{\lambda_c}{w+\lambda_c} \qquad f_m(t) = \lambda_m e^{-\gamma\lambda_m t}; \quad f_m^*(w) = \frac{\lambda_m}{w+\lambda_m}$$

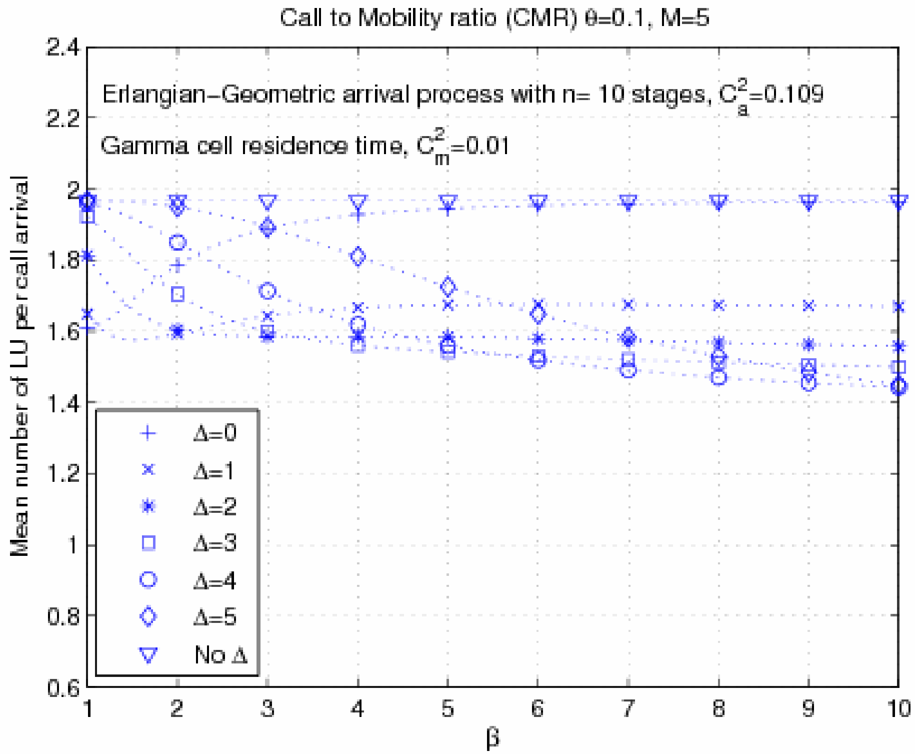


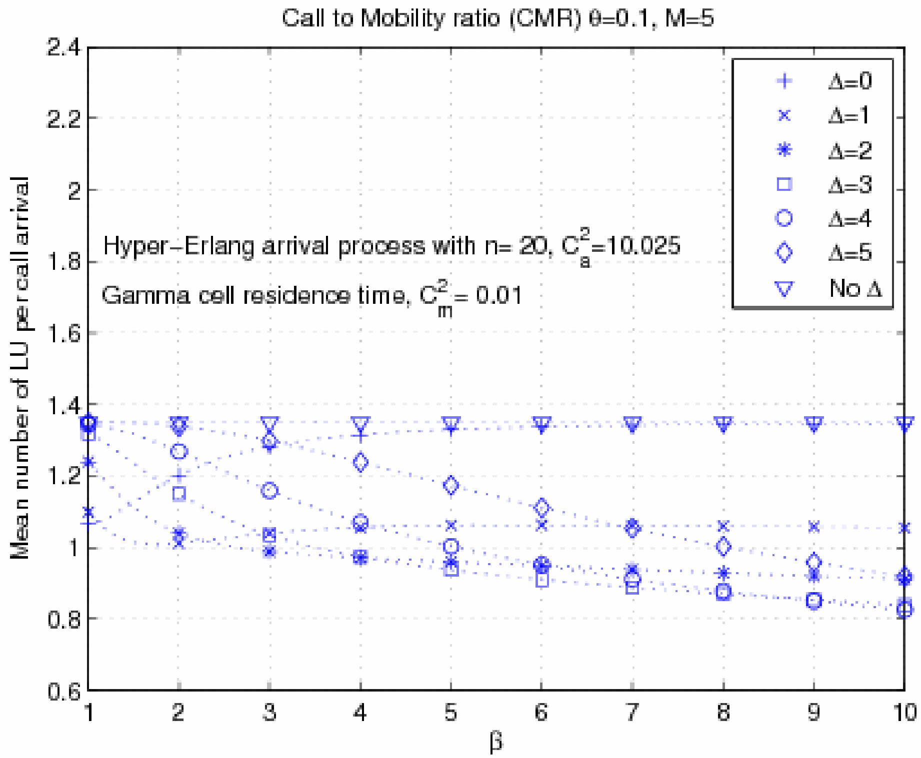
LU: Some illustrative results -i-

$$f^*_{c,e}(w) = \prod_{i=0}^{n-1} \frac{\lambda_i}{w+\lambda_i}; \qquad \lambda_i = \frac{\lambda_c}{a^i}\frac{1-a^n}{1-a}$$

$$f^*_{c,h}(w) = a\frac{\lambda_1}{w+\lambda_1} + (1-a)\frac{\lambda_2}{w+\lambda_2};$$

$$\lambda_2 = n\lambda_1; \quad \frac{1}{\lambda_c} = \frac{a}{\lambda_1} + \frac{1-a}{n\lambda_1}$$





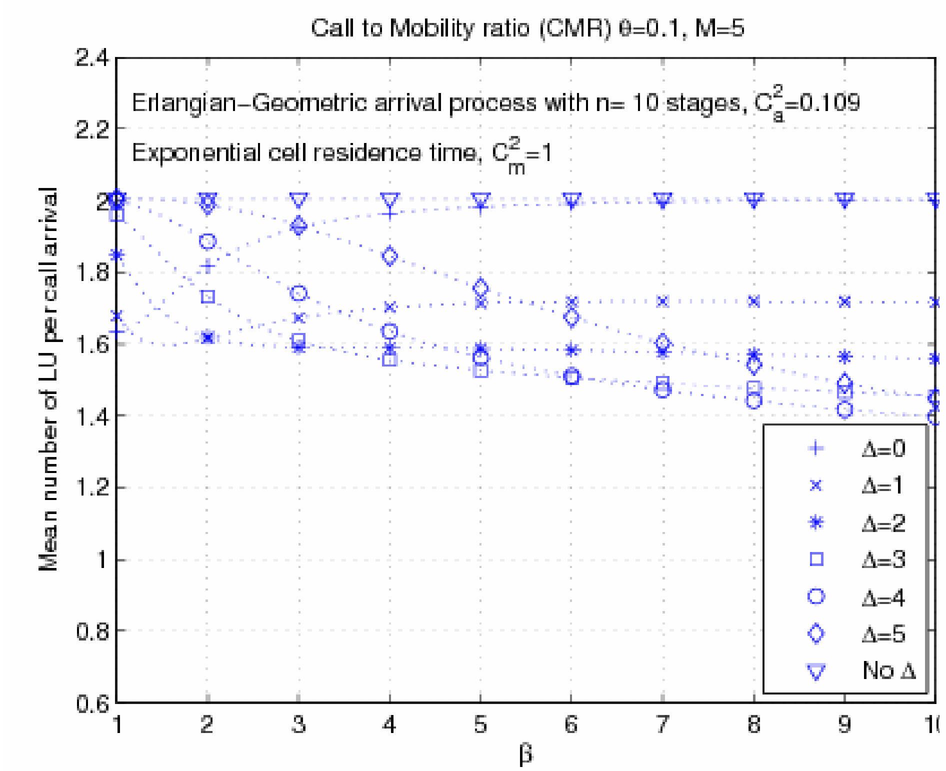
$$f_m(t) = \frac{(\gamma\lambda_m)^\gamma t^{\lambda-1}}{\Gamma(\gamma)} e^{-\gamma\lambda_m t}; \qquad f^*_m(w) = \left(\frac{\gamma\lambda_m}{w+\gamma\lambda_m}\right)^\gamma$$

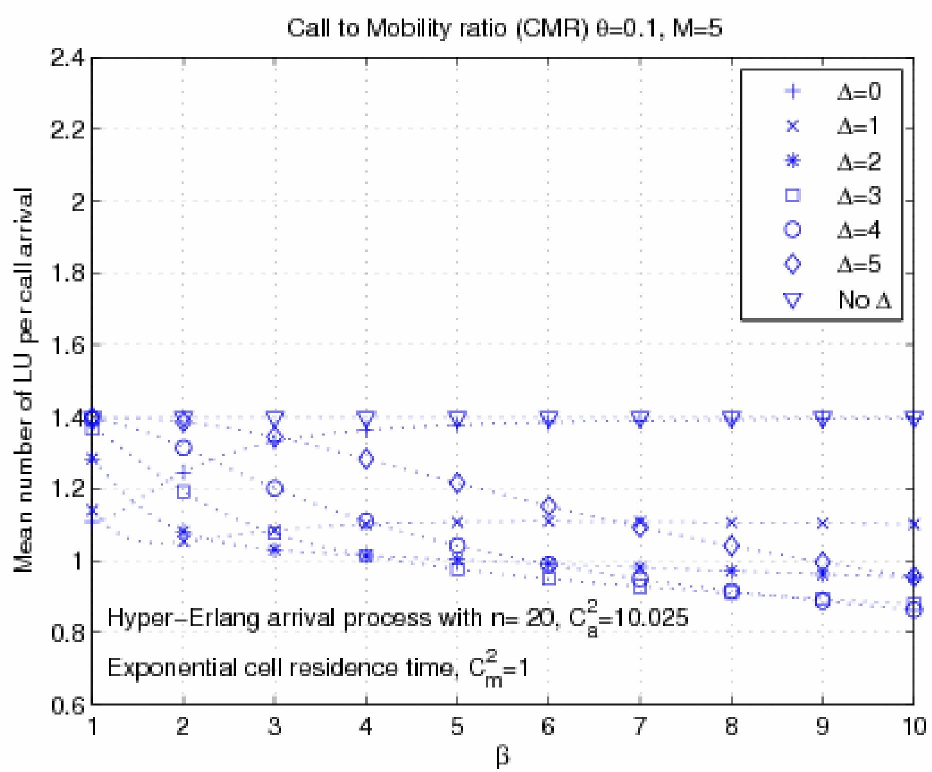
LU: Some illustrative results -ii-

$$f^*_{c,e}(w)=\prod_{i=0}^{n-1}\frac{\lambda_i}{w+\lambda_i};\qquad \lambda_i=\frac{\lambda_c}{a^i}\,\frac{1-a^n}{1-a}$$

$$f^*_{c,h}(w)=a\frac{\lambda_1}{w+\lambda_1}+(1-a)\frac{\lambda_2}{w+\lambda_2};$$

$$\lambda_2=n\lambda_1;\quad \frac{1}{\lambda_c}=\frac{a}{\lambda_1}+\frac{1-a}{n\lambda_1}$$





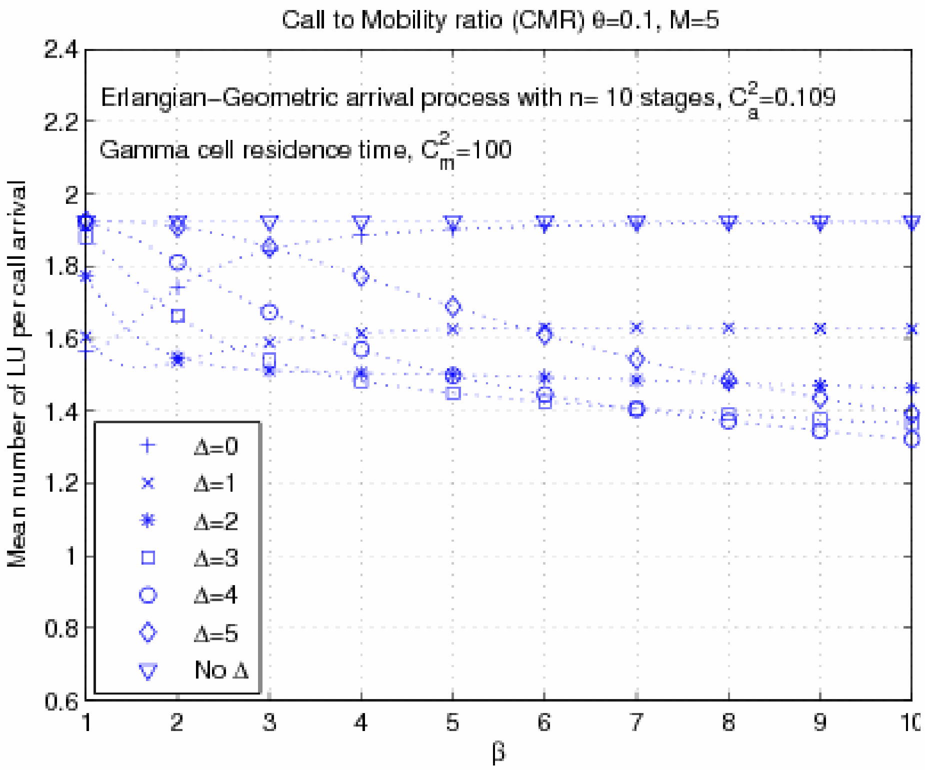
$$f_m(t)=\frac{(\gamma\lambda_m)^{\gamma}\,t^{\lambda-1}}{\Gamma(\gamma)}e^{-\gamma\lambda_m t};\qquad f^*_m(w)=\left(\frac{\gamma\lambda_m}{w+\gamma\lambda_m}\right)^{\gamma}$$

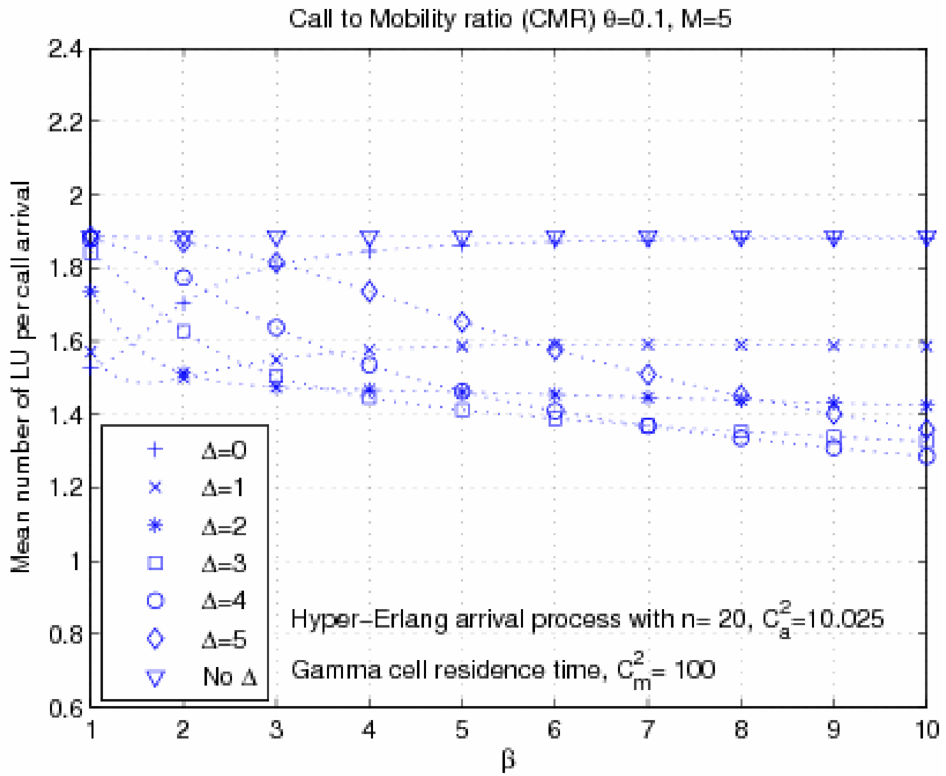
LU: Some illustrative results -iii-

$$f_{c,e}^*(w) = \prod_{i=0}^{n-1} \frac{\lambda_i}{w+\lambda_i}; \qquad \lambda_i = \frac{\lambda_c}{a^i}\frac{1-a^n}{1-a}$$

$$f_{c,h}^*(w) = a\frac{\lambda_1}{w+\lambda_1} + (1-a)\frac{\lambda_2}{w+\lambda_2};$$

$$\lambda_2 = n\lambda_1; \quad \frac{1}{\lambda_c} = \frac{a}{\lambda_1} + \frac{1-a}{n\lambda_1}$$





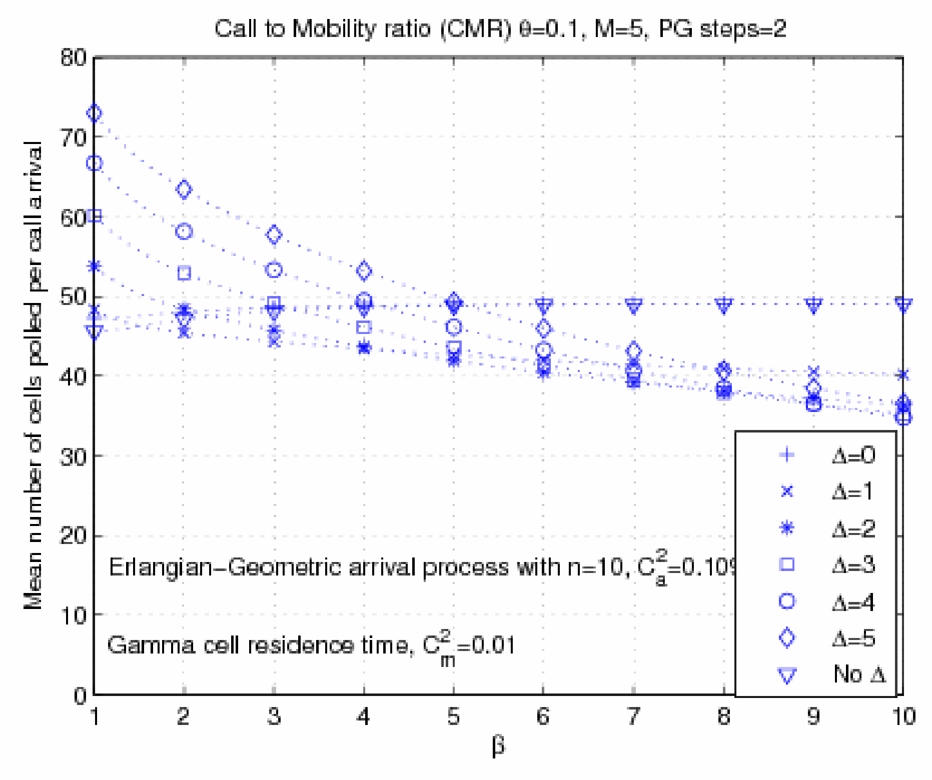
$$f_m(t) = \frac{(\gamma\lambda_m)^\gamma t^{\lambda-1}}{\Gamma(\gamma)} e^{-\gamma\lambda_m t}; \quad f_m^*(w) = \left(\frac{\gamma\lambda_m}{w+\gamma\lambda_m}\right)^\gamma$$

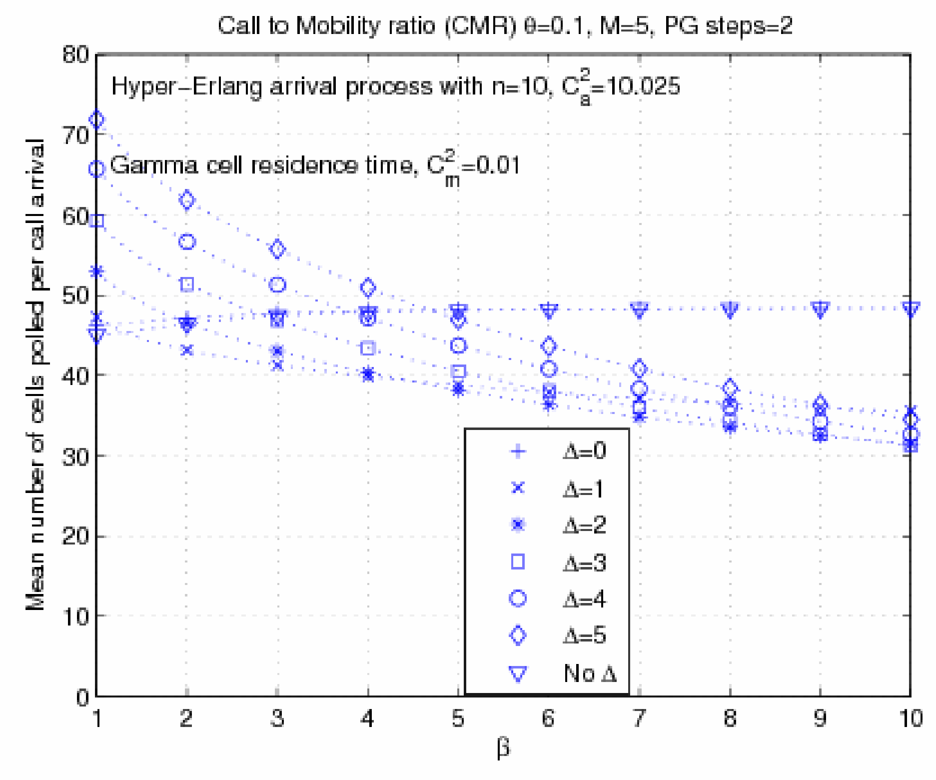
PG with 2 steps: Some illustrative results -i-

$$f_{c,e}^{*}(w) = \prod_{i=0}^{n-1} \frac{\lambda_i}{w+\lambda_i}; \qquad \lambda_i = \frac{\lambda_c}{a^i}\frac{1-a^n}{1-a}$$

$$f_{c,h}^{*}(w) = a\frac{\lambda_1}{w+\lambda_1} + (1-a)\frac{\lambda_2}{w+\lambda_2};$$

$$\lambda_2 = n\lambda_1; \quad \frac{1}{\lambda_c} = \frac{a}{\lambda_1} + \frac{1-a}{n\lambda_1}$$





$$f_m(t) = \frac{(\gamma\lambda_m)^{\gamma} t^{\lambda-1}}{\Gamma(\gamma)} e^{-\gamma\lambda_m t}; \qquad f_m^{*}(w) = \left(\frac{\gamma\lambda_m}{w+\gamma\lambda_m}\right)^{\gamma}$$

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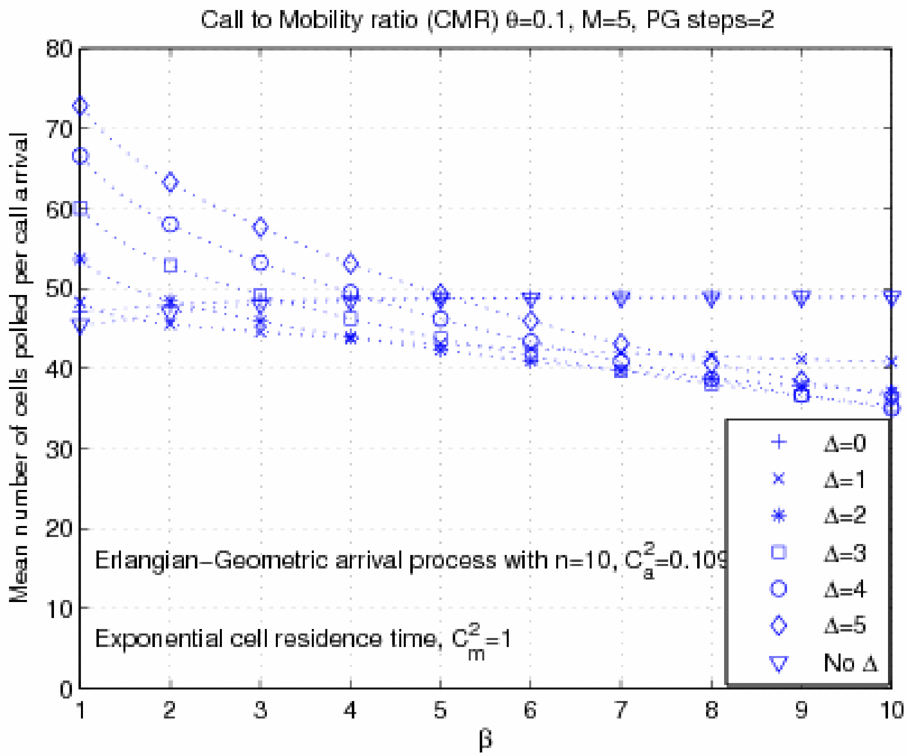
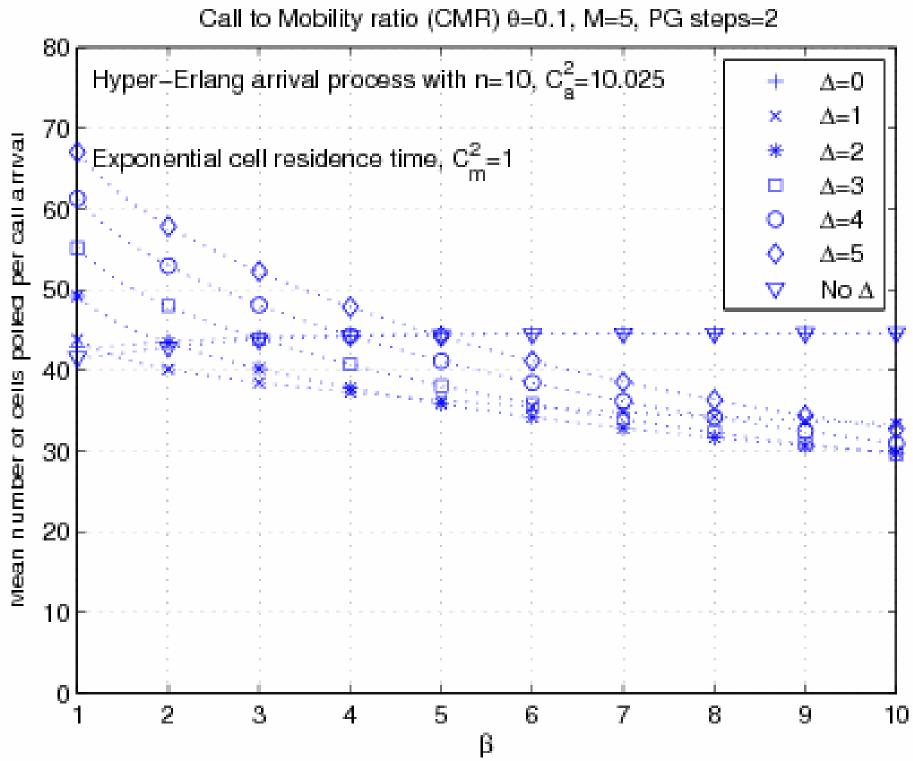
PG with 2 steps: Some illustrative results -ii-

$$f_{c,e}^{*}(w)=\prod_{i=0}^{n-1}\frac{\lambda_i}{w+\lambda_i}; \qquad \lambda_i=\frac{\lambda_c}{a^i}\frac{1-a^n}{1-a}$$

$$f_{c,h}^{*}(w)=a\frac{\lambda_1}{w+\lambda_1}+(1-a)\frac{\lambda_2}{w+\lambda_2};$$

$$\lambda_2=n\lambda_1; \quad \frac{1}{\lambda_c}=\frac{a}{\lambda_1}+\frac{1-a}{n\lambda_1}$$





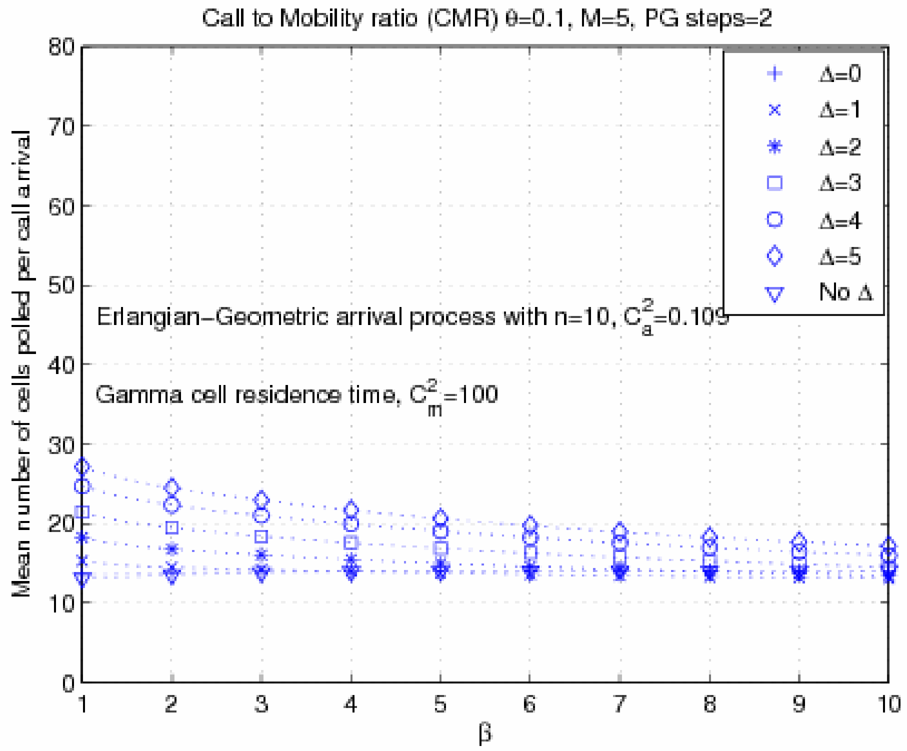
$$f_m(t)=\frac{(\gamma\lambda_m)^{\gamma}t^{\lambda-1}}{\Gamma(\gamma)}e^{-\gamma\lambda_m t}; \qquad f_m^{*}(w)=\left(\frac{\gamma\lambda_m}{w+\gamma\lambda_m}\right)^{\gamma}$$

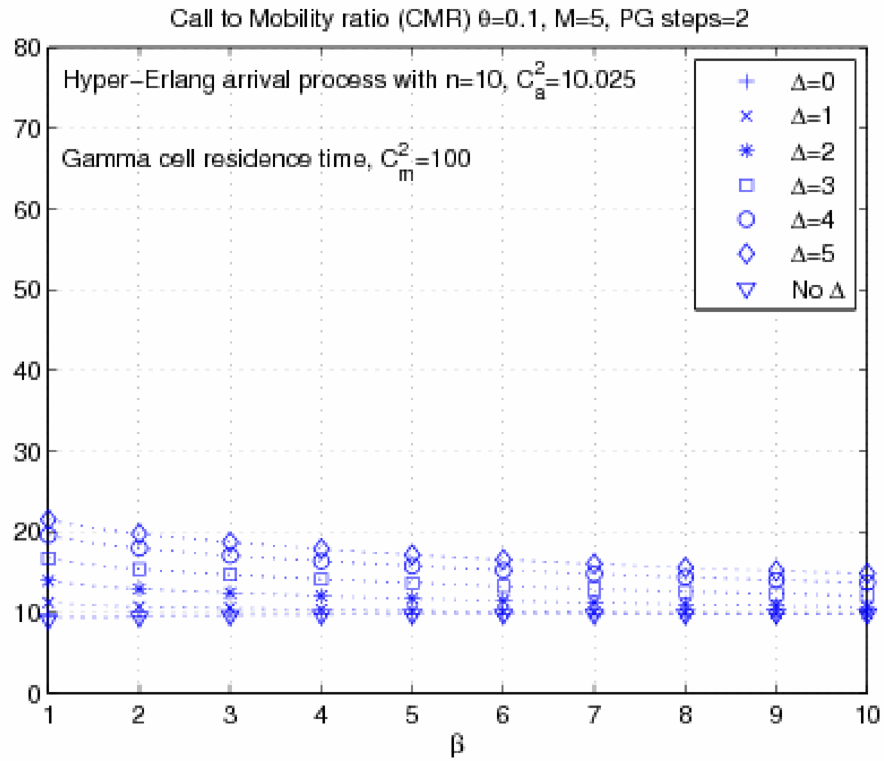
PG with 2 steps: Some illustrative results -iii-

$$f^*_{c,e}(w)=\prod_{i=0}^{n-1}\frac{\lambda_i}{w+\lambda_i};\qquad \lambda_i=\frac{\lambda_c}{a^i}\frac{1-a^n}{1-a}$$

$$f^*_{c,h}(w)=a\frac{\lambda_1}{w+\lambda_1}+(1-a)\frac{\lambda_2}{w+\lambda_2};$$

$$\lambda_2=n\lambda_1;\ \frac{1}{\lambda_c}=\frac{a}{\lambda_1}+\frac{1-a}{n\lambda_1}$$





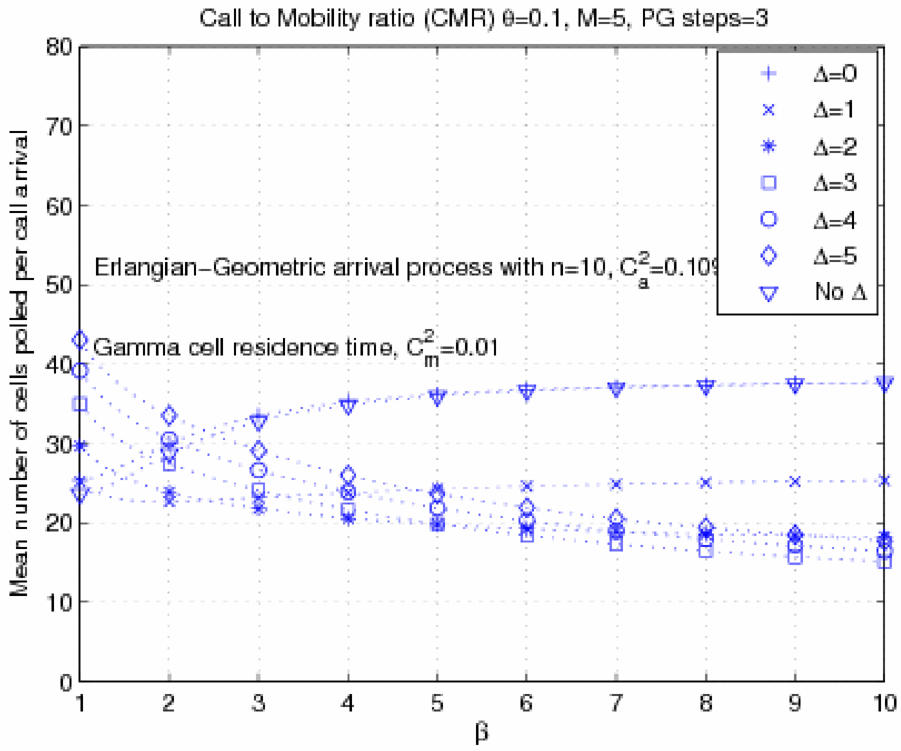
$$f_m(t)=\frac{(\gamma\lambda_m)^\gamma t^{\lambda-1}}{\Gamma(\gamma)}e^{-\gamma\lambda_m t};\qquad f^*_m(w)=\left(\frac{\gamma\lambda_m}{w+\gamma\lambda_m}\right)^\gamma$$

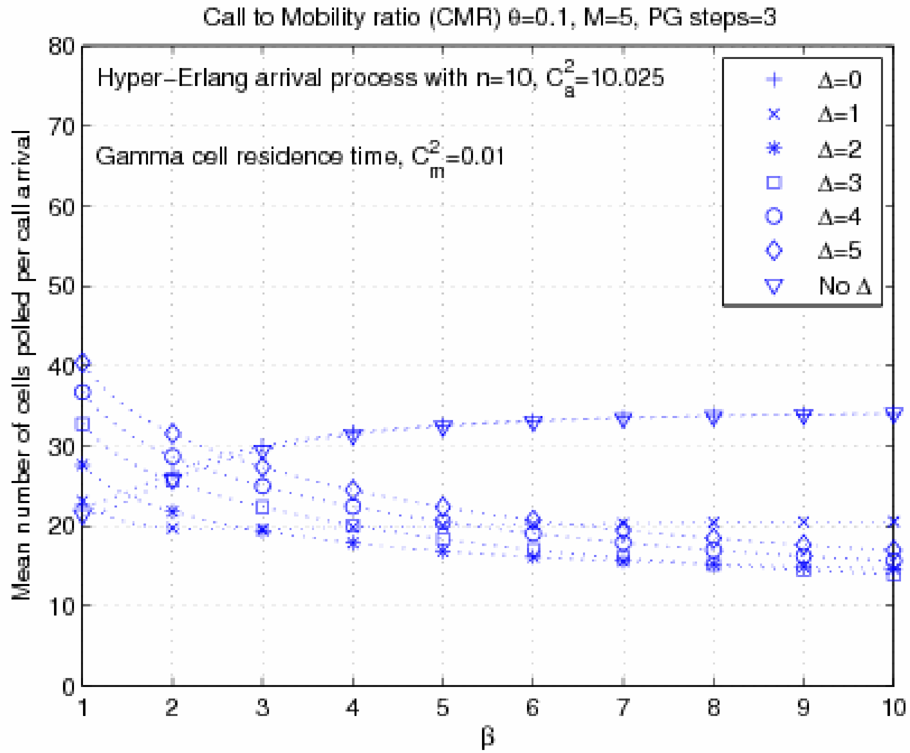
PG with 3 steps: Some illustrative results -i-

$$f^*_{c,e}(w)=\prod_{i=0}^{n-1}\frac{\lambda_i}{w+\lambda_i};\qquad \lambda_i=\frac{\lambda_c}{a^i}\frac{1-a^n}{1-a}$$

$$f^*_{c,h}(w)=a\frac{\lambda_1}{w+\lambda_1}+(1-a)\frac{\lambda_2}{w+\lambda_2};$$

$$\lambda_2=n\lambda_1;\ \frac{1}{\lambda_c}=\frac{a}{\lambda_1}+\frac{1-a}{n\lambda_1}$$





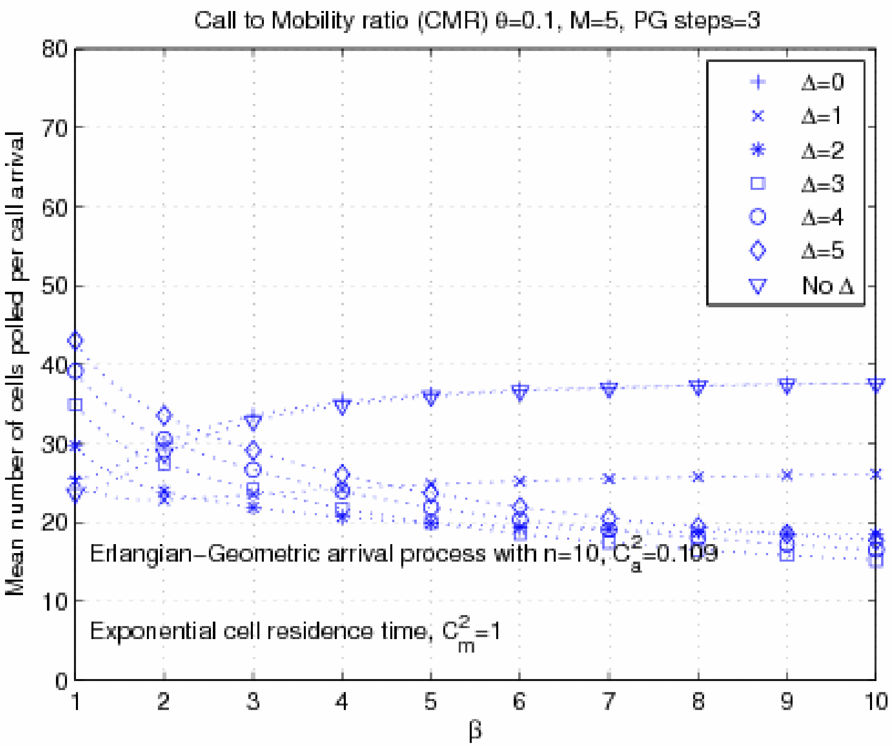
$$f_m(t)=\frac{(\gamma\lambda_m)^{\gamma}t^{\lambda-1}}{\Gamma(\gamma)}e^{-\gamma\lambda_m t};\qquad f^*_m(w)=\left(\frac{\gamma\lambda_m}{w+\gamma\lambda_m}\right)^{\gamma}$$

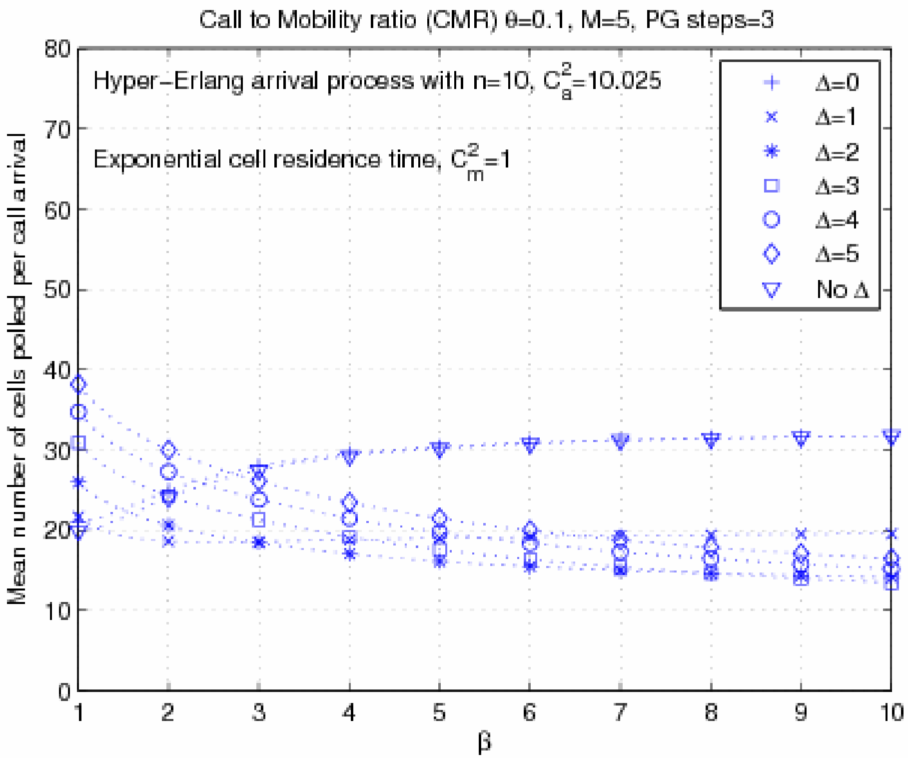
PG with 3 steps: Some illustrative results -ii-

$$f_{c,e}^{*}(w) = \prod_{i=0}^{n-1} \frac{\lambda_i}{w+\lambda_i}; \qquad \lambda_i = \frac{\lambda_c}{a^i}\frac{1-a^n}{1-a}$$

$$f_{c,h}^{*}(w) = a\frac{\lambda_1}{w+\lambda_1} + (1-a)\frac{\lambda_2}{w+\lambda_2};$$

$$\lambda_2 = n\lambda_1; \quad \frac{1}{\lambda_c} = \frac{a}{\lambda_1} + \frac{1-a}{n\lambda_1}$$





$$f_m(t) = \frac{(\gamma\lambda_m)^{\gamma}\, t^{\lambda-1}}{\Gamma(\gamma)} e^{-\gamma\lambda_m t}; \qquad f_m^{*}(w) = \left(\frac{\gamma\lambda_m}{w+\gamma\lambda_m}\right)^{\gamma}$$

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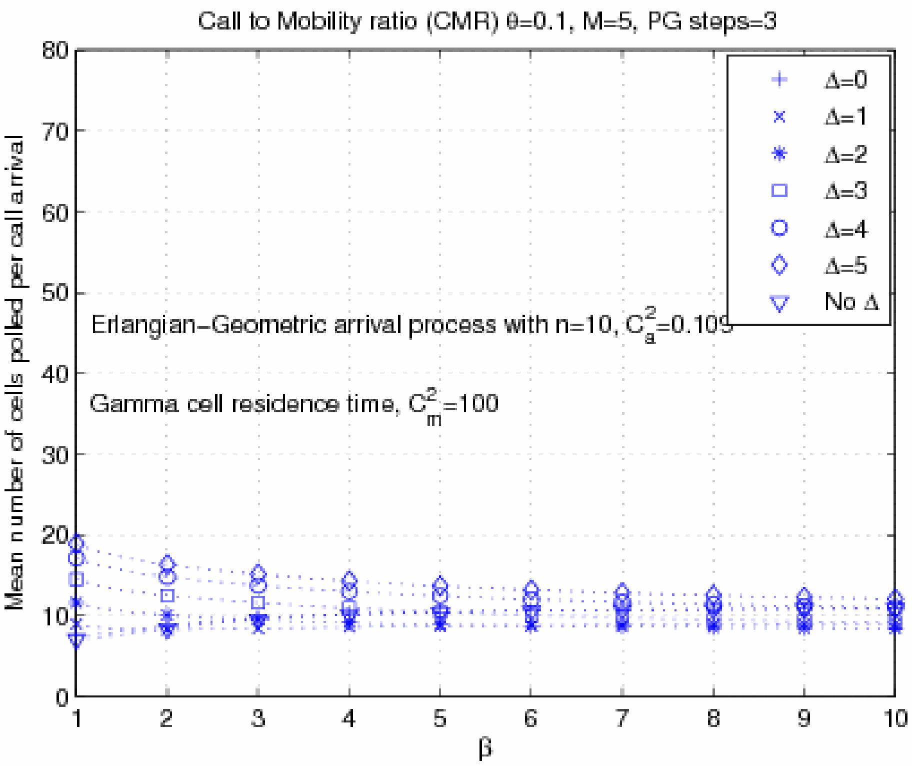
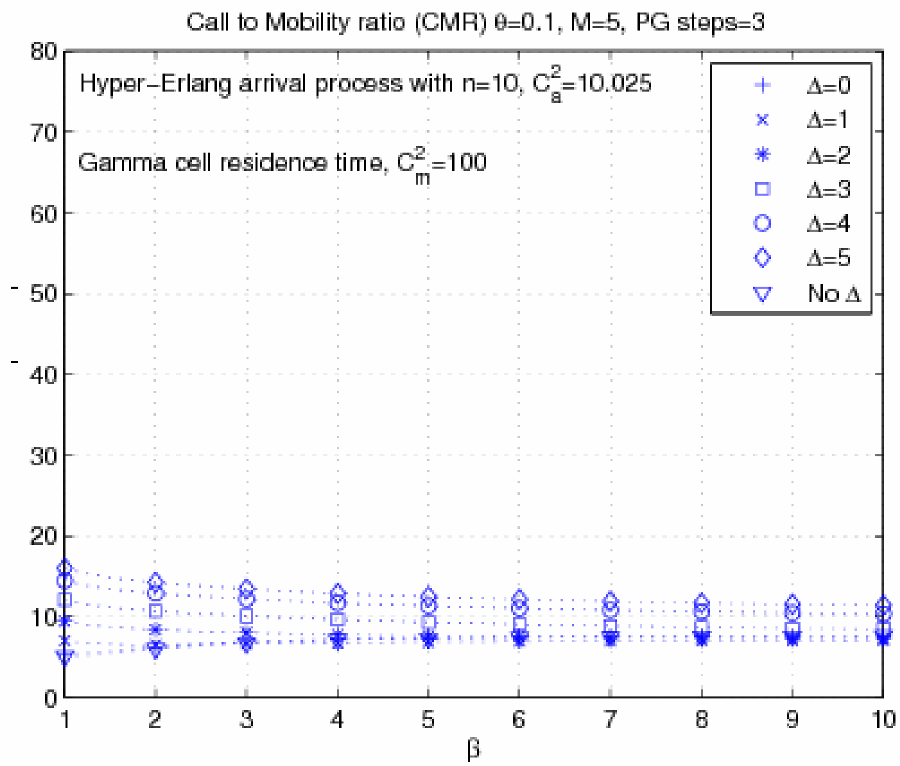
PG with 3 steps: Some illustrative results -iii-

$$f_{c,e}^{*}(w)=\prod_{i=0}^{n-1}\frac{\lambda_i}{w+\lambda_i}; \qquad \lambda_i=\frac{\lambda_c}{a^i}\frac{1-a^n}{1-a}$$

$$f_{c,h}^{*}(w)=a\frac{\lambda_1}{w+\lambda_1}+(1-a)\frac{\lambda_2}{w+\lambda_2};$$

$$\lambda_2=n\lambda_1; \ \frac{1}{\lambda_c}=\frac{a}{\lambda_1}+\frac{1-a}{n\lambda_1}$$





$$f_m(t)=\frac{(\gamma\lambda_m)^{\gamma}t^{\lambda-1}}{\Gamma(\gamma)}e^{-\gamma\lambda_m t}; \quad f_m^{*}(w)=\left(\frac{\gamma\lambda_m}{w+\gamma\lambda_m}\right)^{\gamma}$$

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Conclusions

- Proposals
  - A **look-ahead movement-based location update** procedure.
  - A simple mobility model to evaluate the above procedure
- The analysis has been carried out:
  - With a 2-D scenario.
  - A 2-D mobility model quite flexible.
- When the mobile terminal shows a predictable trajectory, better results, in terms of less signaling traffic supported in the Air Interface, can be obtained by using look-ahead location tracking strategies.

Thanks very much indeed
for your attention!