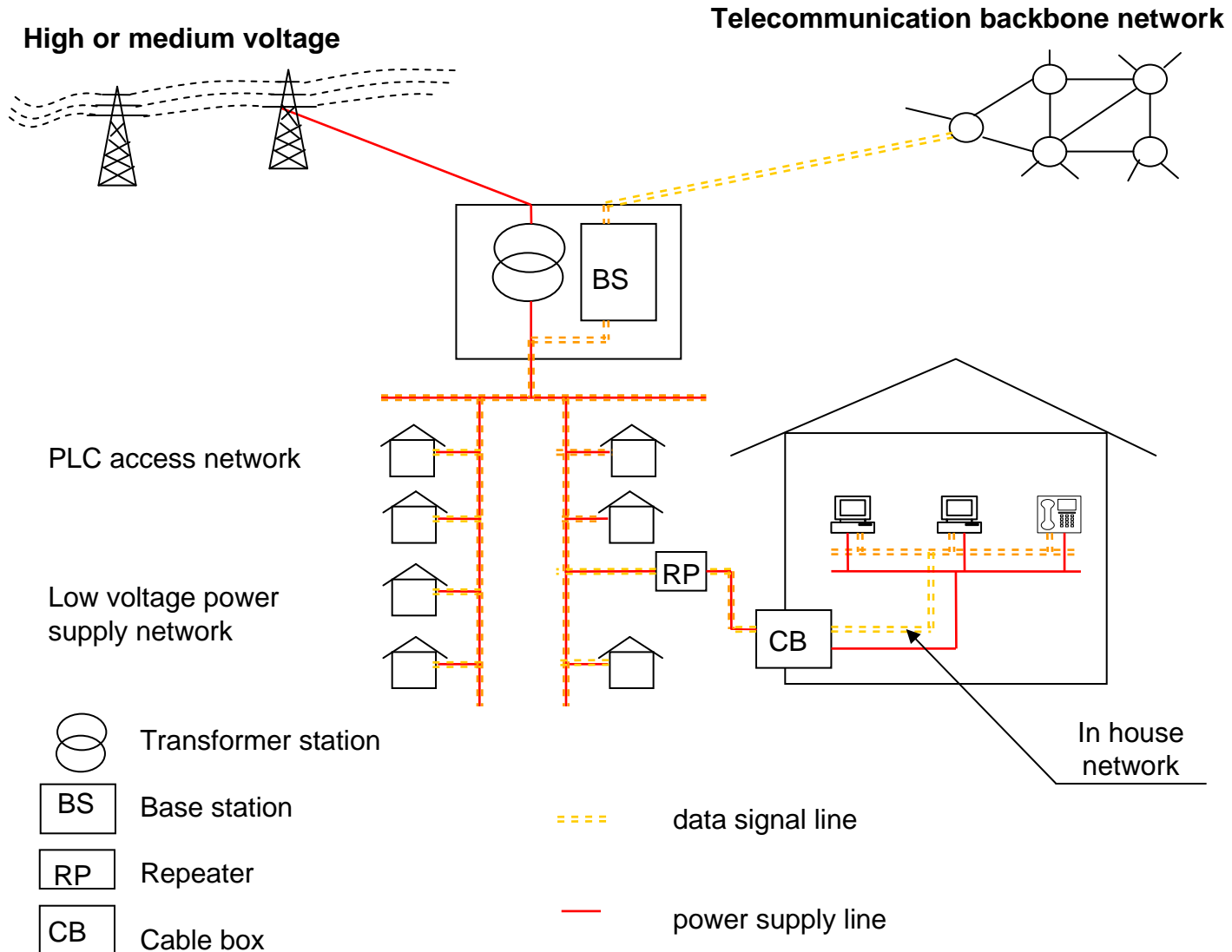
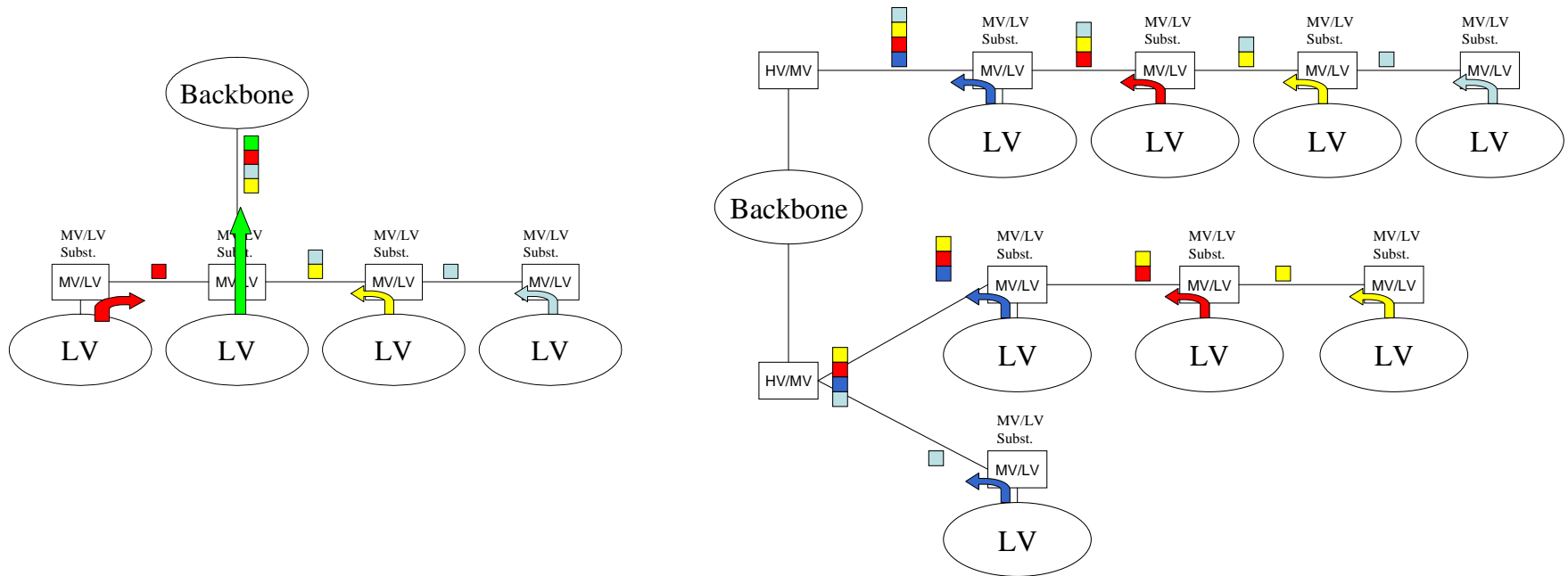

A Channel Self-Organizing Protocol for Multi-Cell PLC Networks

Le Phu Do
ITG-FG-5.2, 07 Oct. 2010



-
- PLC Networks with Multi-Cell Structure
 - Sharing Transmission Capacity between Multiple PLC Cells
 - Realization of Channels
 - Solution Proposal
 - Communication between Cells
 - Algorithm Description
 - Example Results
 - Conclusions



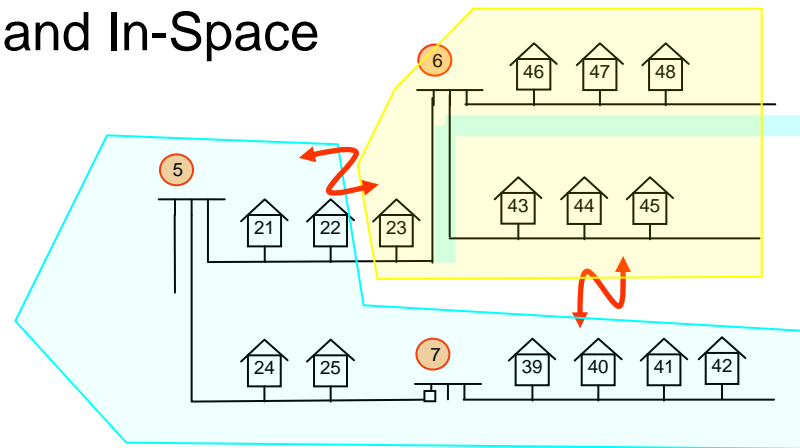


- LV: Low Voltage
- MV: Medium Voltage
- HV: High Voltage

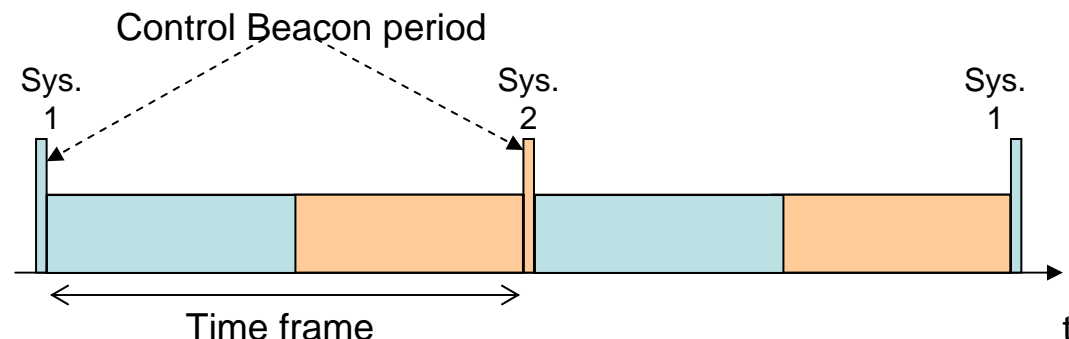
Source: OPERA



- Interference: In-Line and In-Space

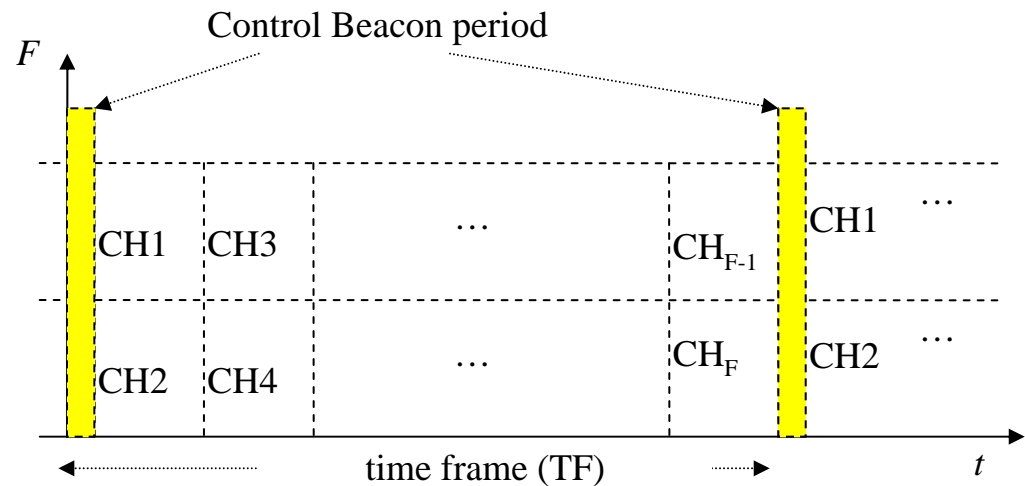


- The Inter Phy Protocol (IPP)*: Ideal: Detection of the neighbor cells by listening to the beacon signal from the neighbors



* Specified in the IEEE P1901

- A Resource Unit (Channel-CH) is configured as
 - Time Slot and Frequency Band
- Dynamic reservation/allocation of channels to each cell based on its number of active users



- To be investigated
 - Channel Reuse: to improve possible transmission capacity
 - Fairness: same reservation resource per active users, in different cells

- Sharing available transmission resource by all cells
- Maximizing the channel reuse: maximizing the transmission capacity of the network
- Fairness between active users in the cells: Same P for all cells
- Calculation of P : Number of allocated channels per number of active users:

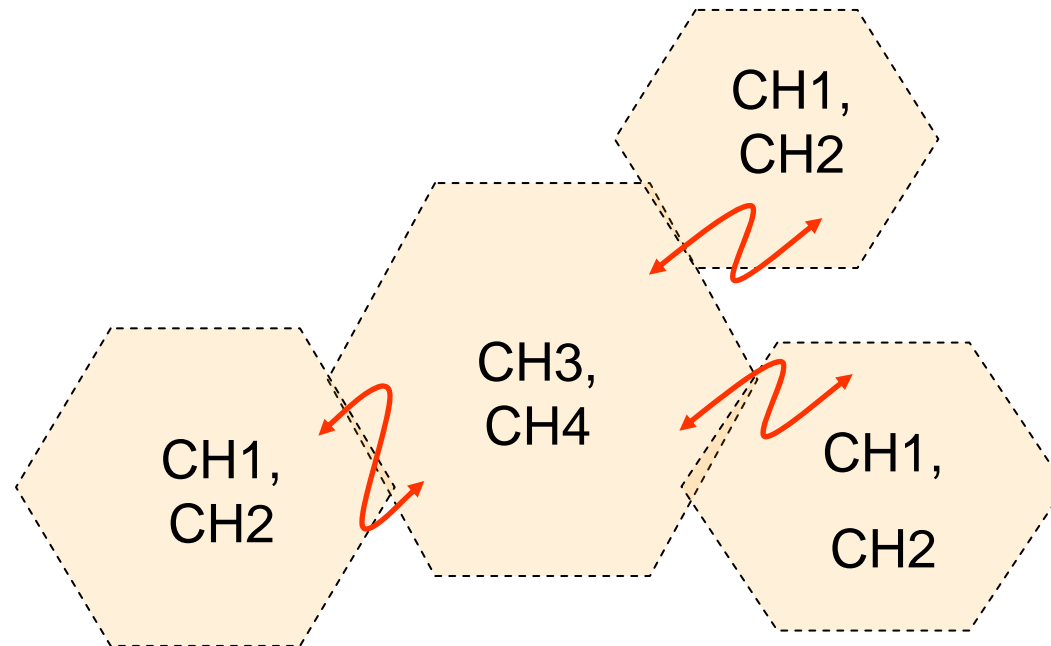
$$P_i = B_{C_i} / N_i$$

N_i : =1 if no active user, =number of active users otherwise

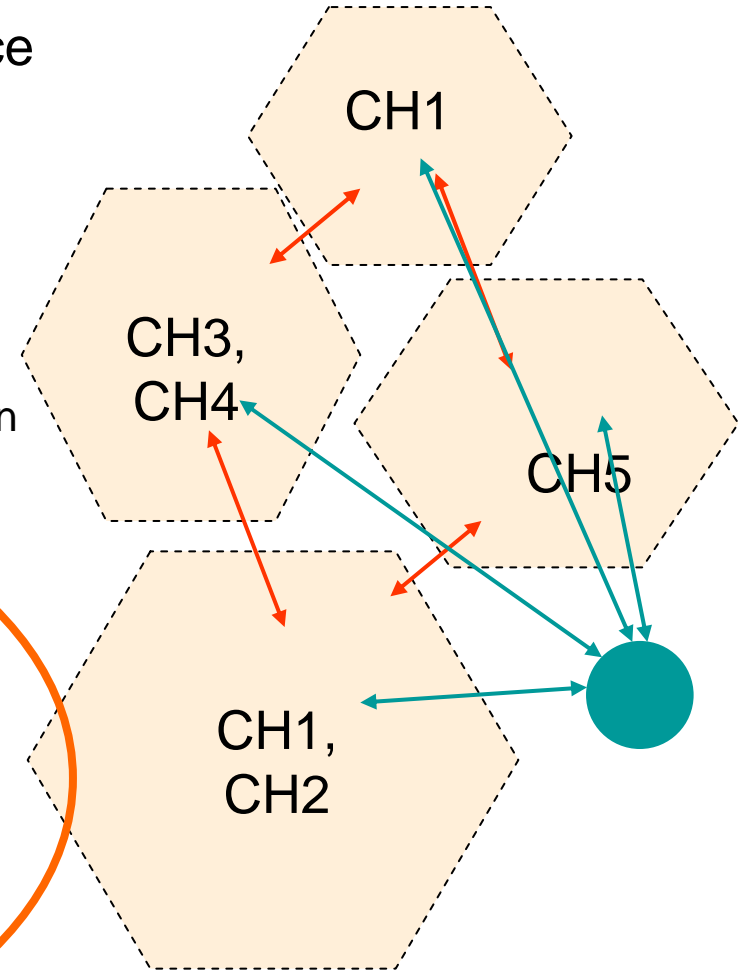
B_{C_i} : Number of allocated channels in cell C_i



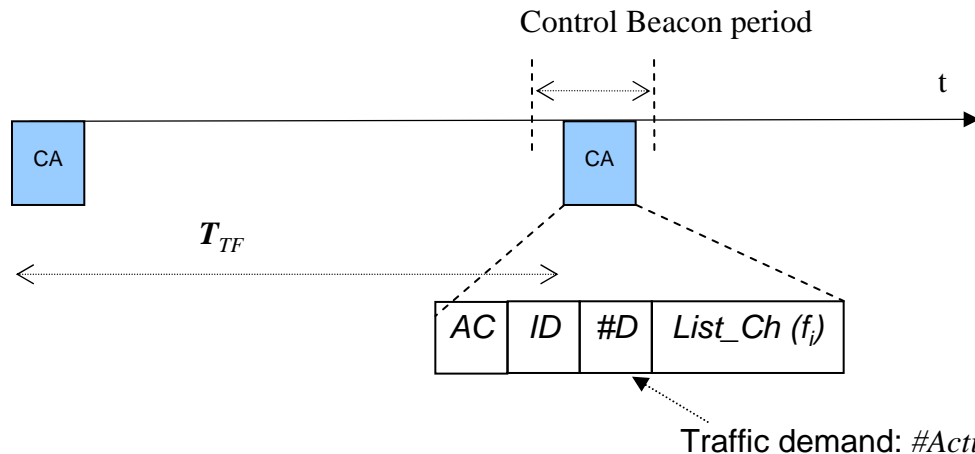
- Static Distribution: Each cell is allocated a fixed amount of channels
 - User changes status (active/idle/off) dynamically -> may be unfair between users in different cells



- Dynamic Distribution: Channels of each cell will be varied according to the resource requirement
 - Centralized (like in the GSM system)
 - Global control of the total capacity, need a control center
 - Require resources for transmission between the control center and the HES
 - Distributed
 - Require communication between neighbor cells
 - Sharing the channel status with neighbors
 - Cell informs its status to its neighbors (in beacon period)
 - Processing received information to allow “moving” channels between cells



- Common Slot and Collision
 - One slot is reserved for inter-cell communications (in beacon period)
 - Format
 - Regular broadcast the “channel announce” message (CA-Msg)
 - Random transmission protocol
 - No collision detection mechanism
 - Effect of collision



AC: 1 Byte: Access or InHome

ID: 6 Byte: Address of the Master

#D: 1 Byte: , of active users

List_Ch(f_i): 2 bit for a channel

• 0: Channel is free

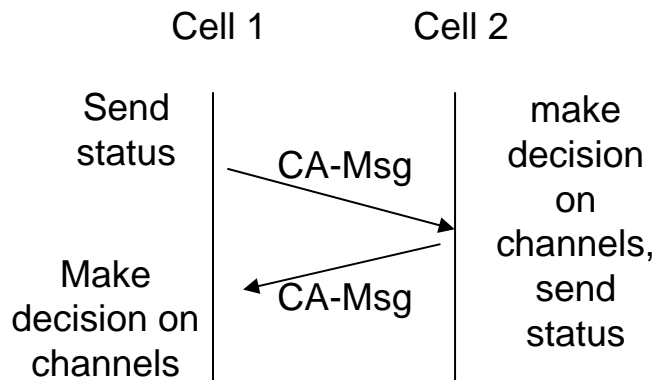
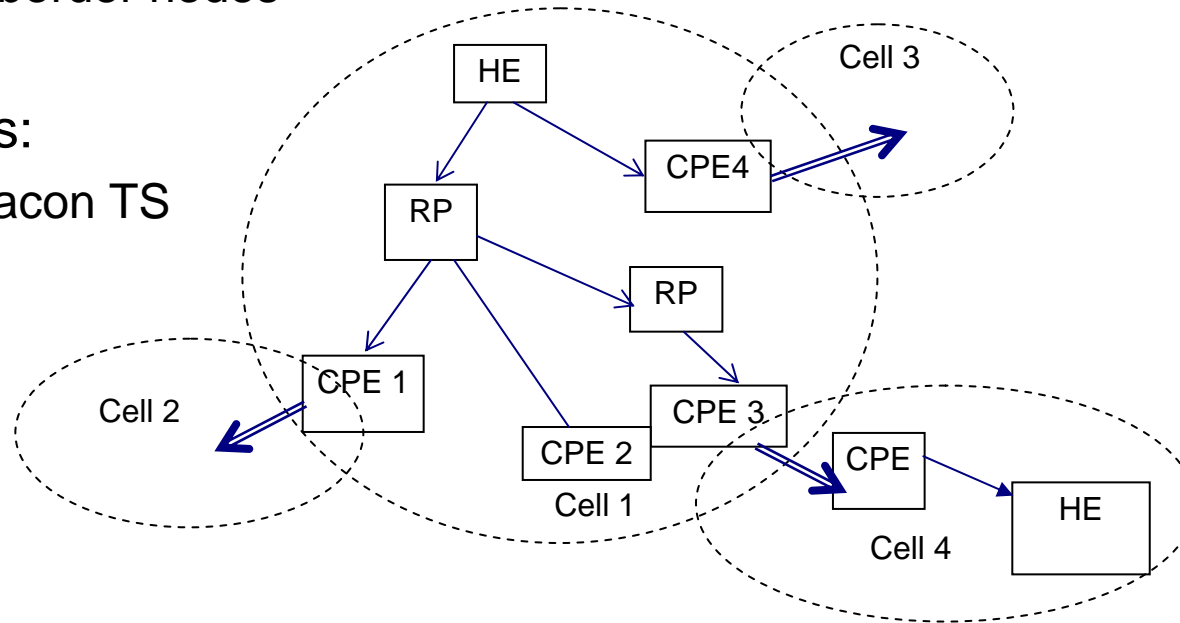
• 1: occupied by this cell

• 2: used by one neighbor cell

• 3: used by more than one neighbor cells

(length of a CA-Msg is 18 Byte for 80 channels)

- Broadcasting of the CA-Msgs
 - Can be carried out by border nodes
- Sending of the CA-Msgs:
 - Randomly select a Beacon TS
 - No ACK



HE: Head end
 RP: Repeater
 CPE: Customer Premise Equipment

→ Transmission in downlink
 ==> Transmission in beacon period
 → Transmission in uplink

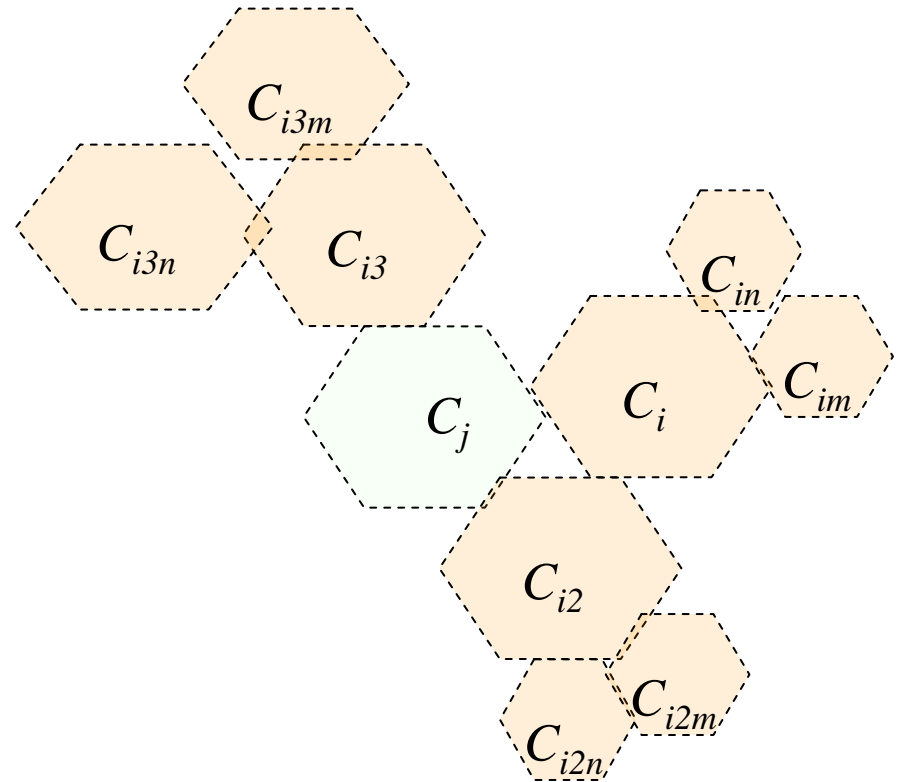


- Probability to select a slot
(1 neighbor has H_i neighbors)

$$p_j^{send(i)} = \frac{1}{H_i + 1}$$

- Probability to select a slot

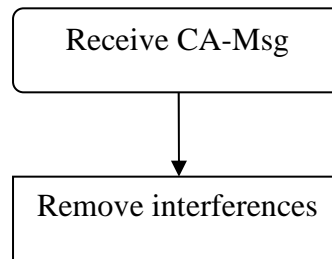
$$p_j^{send} = \frac{1}{H_j} \cdot \sum_{C_i^{(j)}} \frac{1}{H_i + 1}$$



- Two objectives \Rightarrow Two procedures

- Maximizing the number of channels allocated in all cells

\Rightarrow Seize Channels

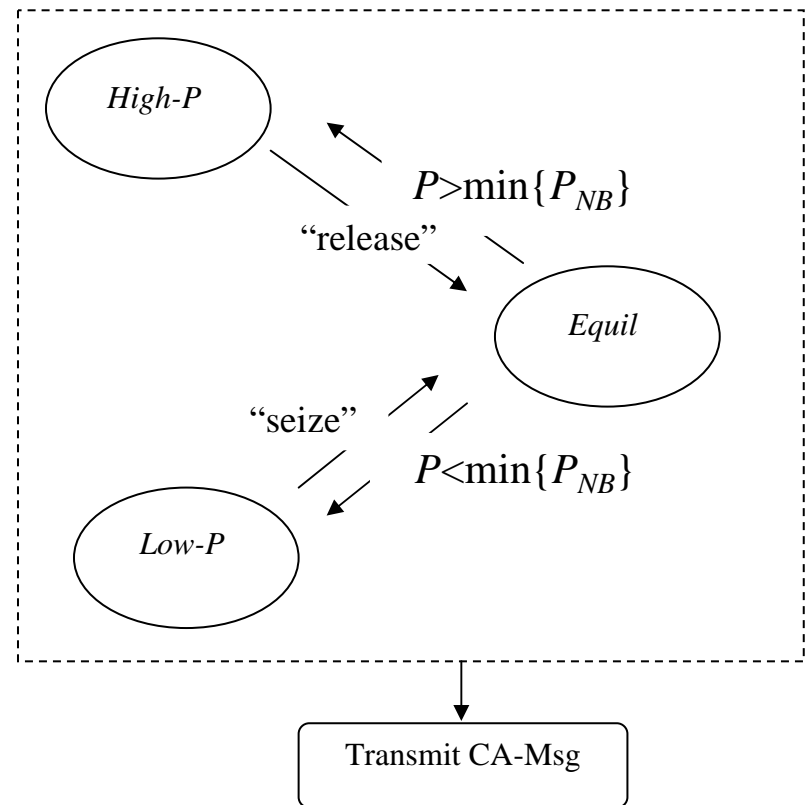


- Same P – fairness (in different cells)

\Rightarrow Release Channels

$$B_{C_i}^- = \left\lfloor \frac{B_{C_i} N_j - B_{C_j} N_i}{N_i + N_j} \right\rfloor$$

P_{NB} : P of neighbor



C_j : neighbor of C_i , which has lowest P



- Channel seize
 - Combine channel in use by its neighbors
 - seize the “unused” channel
- Channel release
 - Compare channel/demand with neighbor (C_j) which has lowest channel/demand
 - Find number of channels has to be released: can be obtained by C_j
 - Not used by neighbors (except this cell) of C_j
- Validity of channel information
 - Each channel announce message has a limit validity
 - time out

Sys.

| | CH1 | CH2 | Ch3 | Ch4 | Ch5 | Ch6 |
|----|-----|-----|-----|-----|-----|-----|
| C1 | | | | | | |
| C3 | | | | | | |

C2

| | | | | | | |
|------|---|---|---|---|---|---|
| Used | | | | | | |
| C2 | 2 | 3 | 2 | 1 | 3 | 3 |

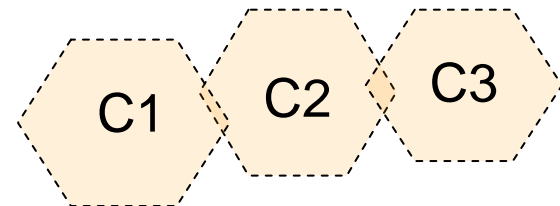
C1

| | CH1 | CH2 | Ch3 | Ch4 | Ch5 | Ch6 |
|--------|-----|-----|-----|-----|-----|-----|
| C1 | | | | | | |
| C2 | 2 | 3 | 2 | 1 | 3 | 3 |
| Ne(C2) | | | | | | |

| | | | | | | |
|---------|--|--|--|--|--|--|
| C1 Rel. | | | | | | |
| C1 | | | | | | |

Sys.

| | | | | | | |
|----|---|---|---|---|---|---|
| C1 | | | | | | |
| C2 | 1 | 3 | 1 | 1 | 3 | 3 |
| C3 | | | | | | |



Given: Set of channels: $\mathbf{F}=\{1,\dots,F\}$, Set of cells: $\mathbf{C}=\{1,\dots,S\}$, Cell C_i contains N_i active users, Same traffic demand from each active user

Channel status:

- Channel usage vector in each Master (Head end-HE): $\text{Ch}_{C_i}=(a_{i,1}, a_{i,2}, a_{i,3}, \dots a_{i,F})$
 where $a_{i,f}=1$: C_i uses channel f , $a_{i,f}=0$: otherwise

To be evaluated:

- Channel reuse factor:

$$f_{CR} = \frac{B_{All}}{F}$$

- Number of allocated channels

$$B_{All} = \sum_{i=1}^S B_{C_i} = \sum_{i=1}^S \sum_{f=1}^F a_{i,f}$$

- Fairness index:

- $\frac{1}{S} \leq F_{All} \leq 1$
- 1: perfect, greater is better

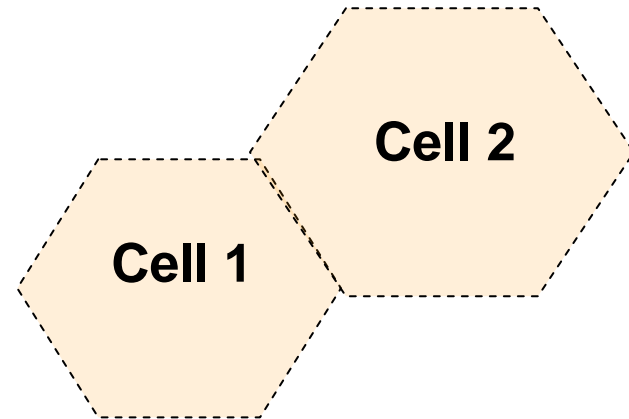
$$F_{All} = \frac{\left(\sum_{i=1}^S \frac{B_{C_i}}{N_i} \right)^2}{S \cdot \sum_{i=1}^S \left(\frac{B_{C_i}}{N_i} \right)^2}$$

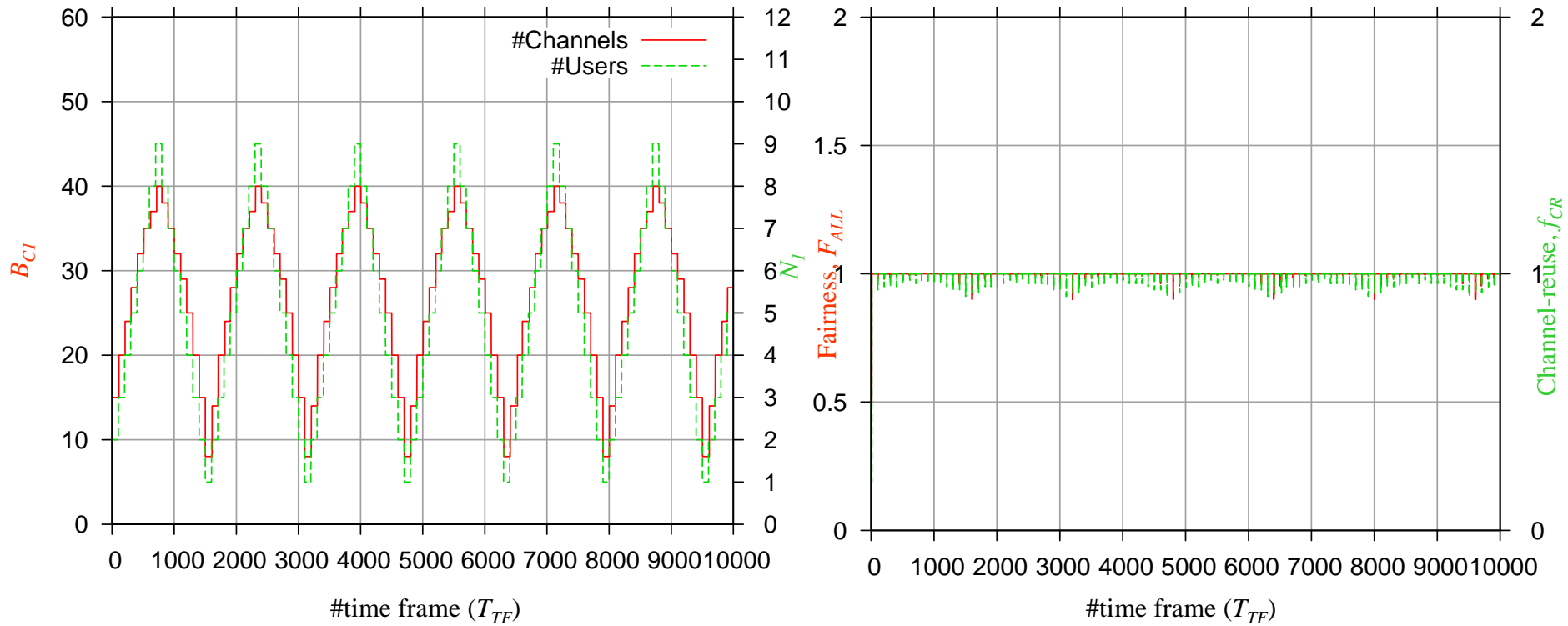
- Interferences

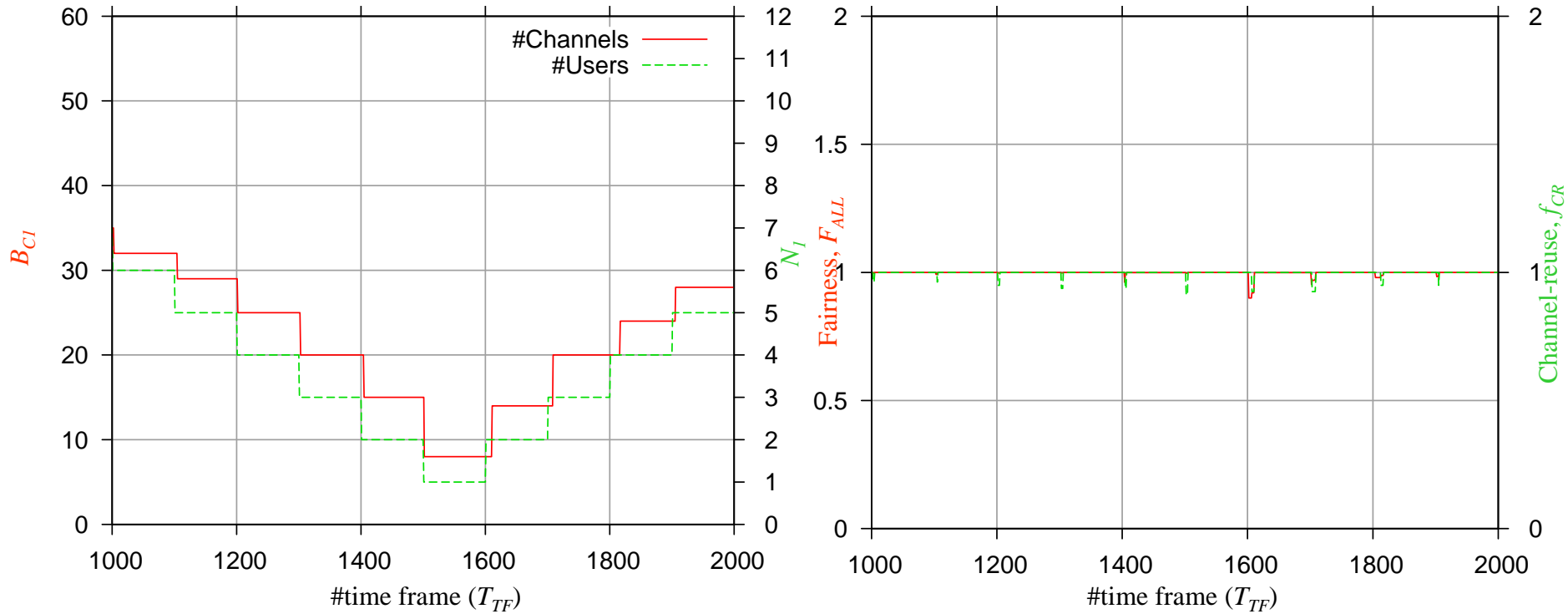
$$I_{All} = \sum_{i=1}^S \sum_{f=1}^F a_{i,f} \sqrt{\sum_{\substack{j=1 \\ j \neq i}}^S a_{j,f}}$$



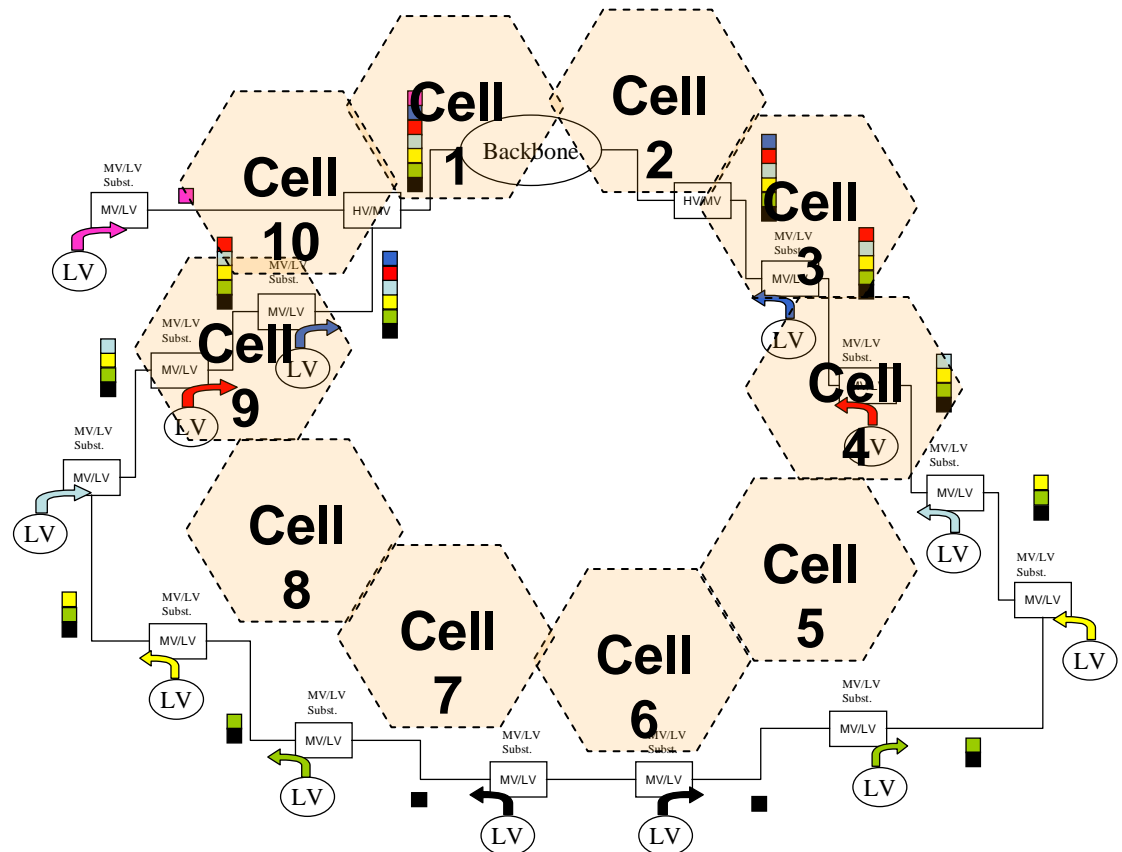
- Two cells ($C_i=2$), are neighbors ($i_{i,j}=1$)
- $F=80$
- C_2 with fixed number of users $N_2 = 9$
- C_1 with increasing and decreasing number of users over the time (every 100TF), between 1 and 9
- $p_1^{send} = p_2^{send} = 0.5$



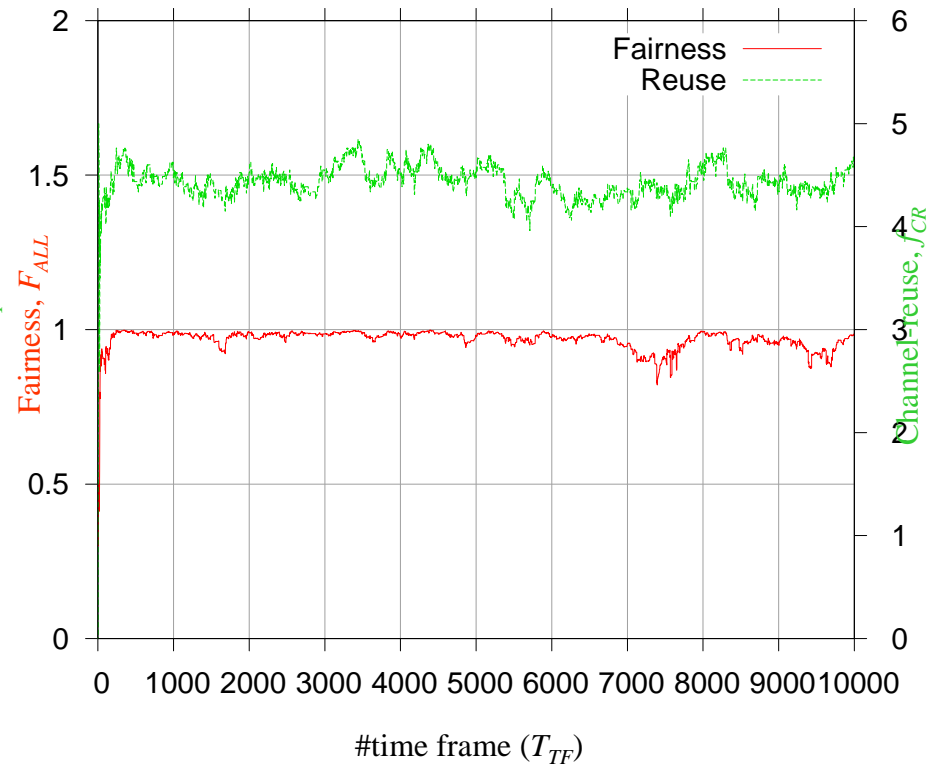
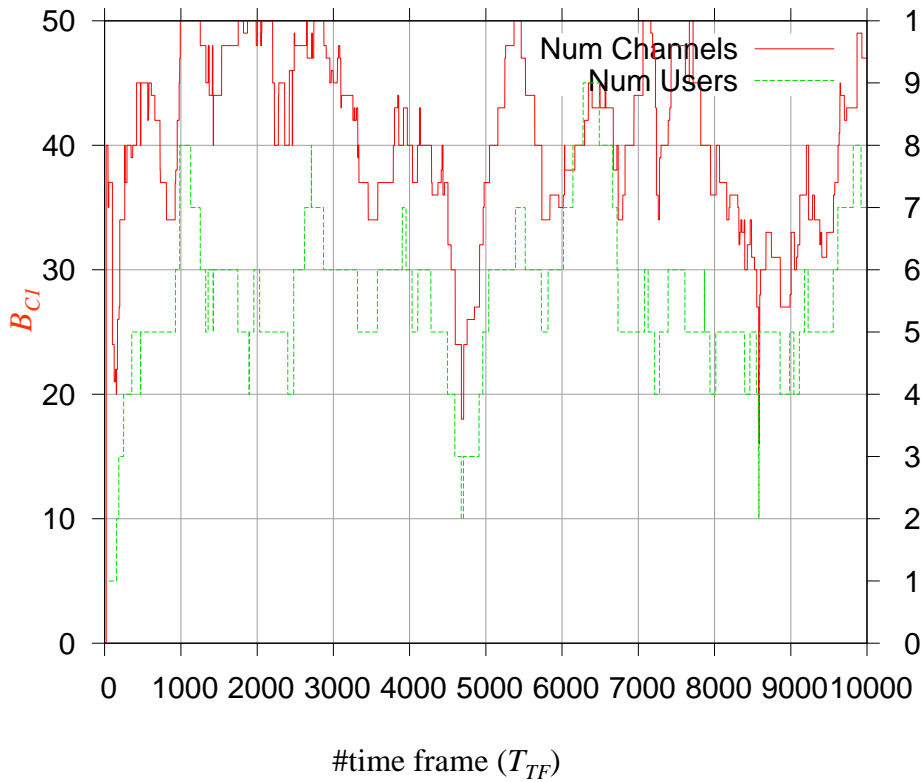


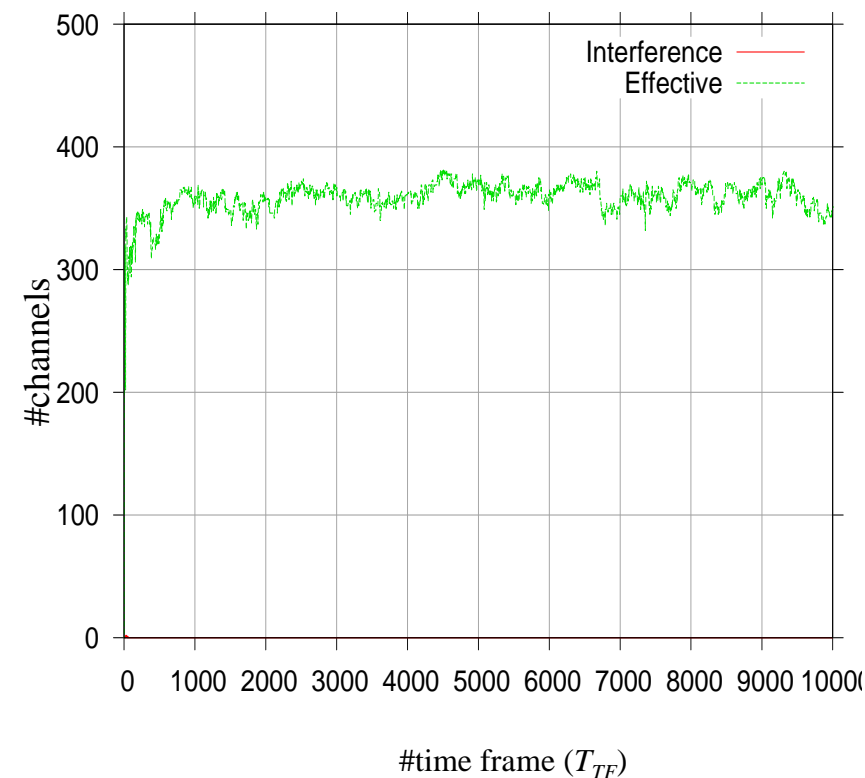
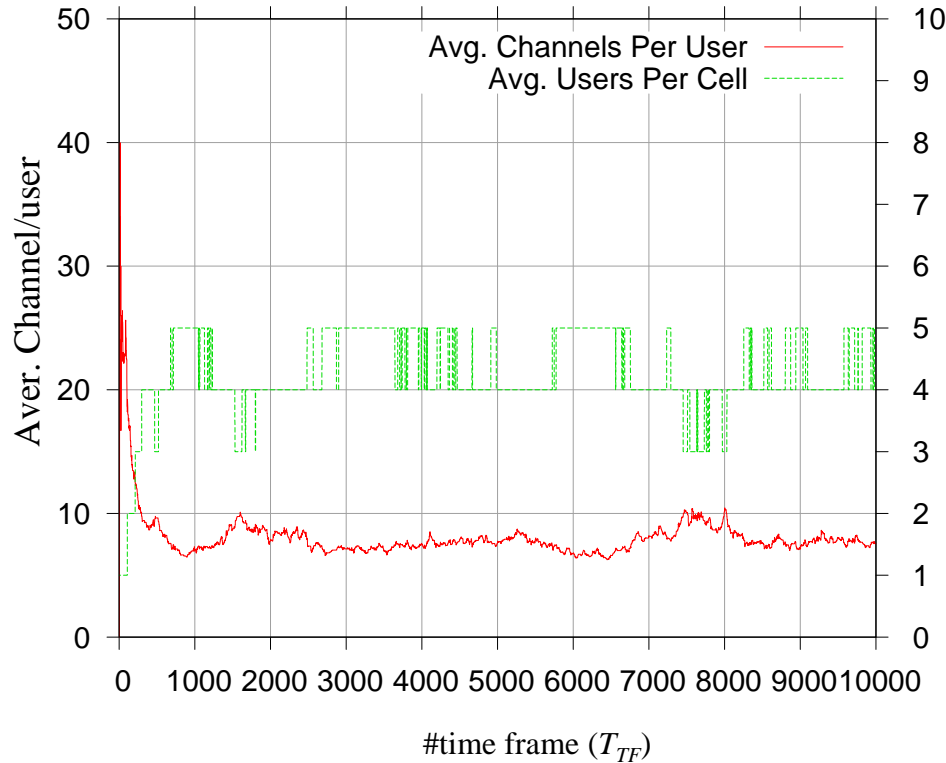


- Ring of 10 cells
- Interferences with two neighbors
- 9 users/cell with on/off model:
- On and Off phases Geo
 - $E\{T_{ON}\} = 100TF$
 - $E\{T_{OFF}\} = 100TF$



Cell1





E.g. If a channel can be used to transmit 1Mbps
 → Average speed/user ≈ 8.2 Mbps

$$\# \text{effective channels} = \# \text{allocated channels} - \# \text{interfering channels}$$



-
- Model for dynamic channel allocation for Multi-Cell PLC supports for changing of traffic demands (user's status)
 - Allow channel self-organizing between cells with the distributed negotiation strategy: No need addition central control unit
 - Required the realization of channel announce messages between neighbor cells
 - Can be applied to Access PLC, In-Home PLC



Thank You!

Ref: L. P. Do, R. Lehnert, "Distributed Dynamic Resource Allocation for Multi-Cell PLC Networks",
13th IEEE International Symposium on Power-Line Communications and Its Applications (IEEE-
ISPLC 2009), Dresden, Germany. 29 Mar-01 Apr. 2009.

