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

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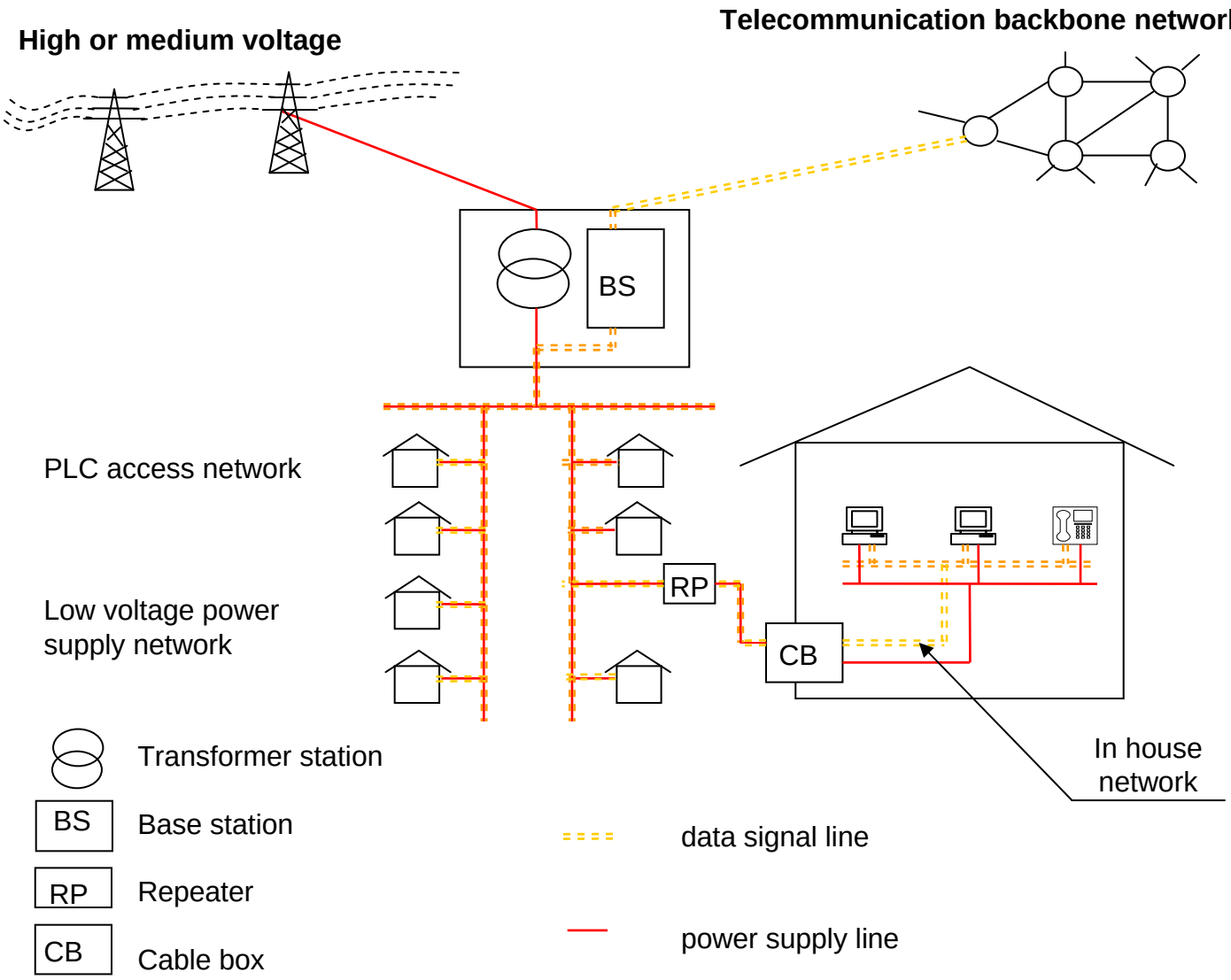
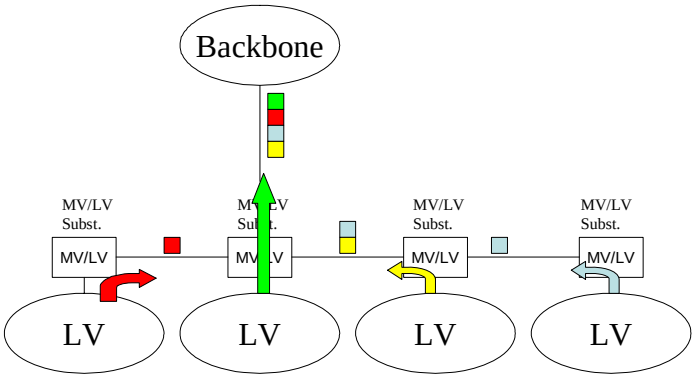
Contents

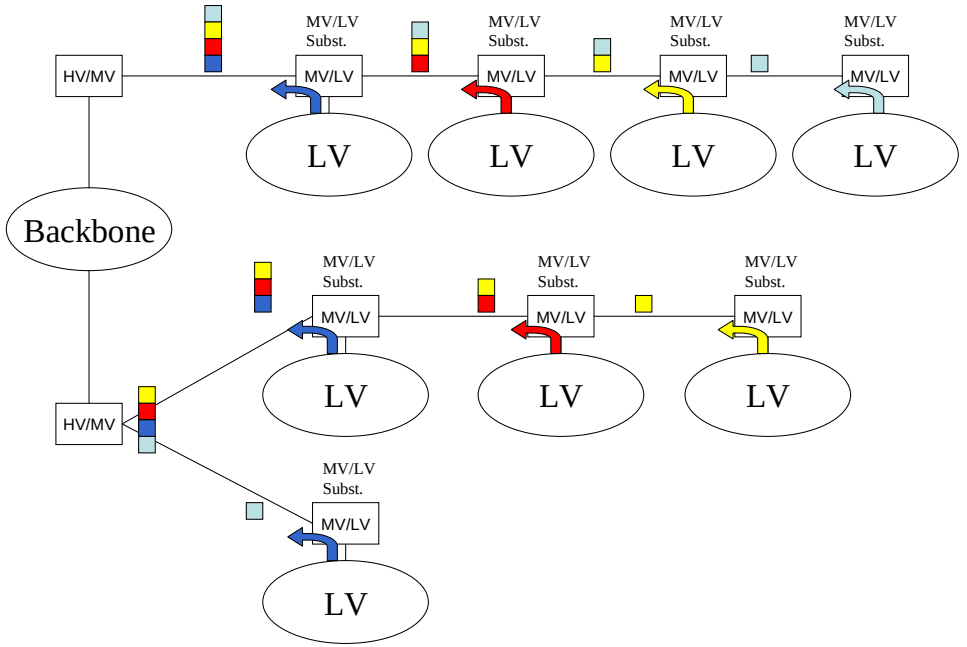
- PLC Networks with Multi-Cell Structure
- Sharing Transmission Capacity between Multiple PLC Cells
- Realization of Channels
- Solution Proposal
  - Communication between Cells
  - Algorithm Description
  - Example Results
- Conclusions

Broadband-PLC Network



Multi-Cell PLC Access Network Examples



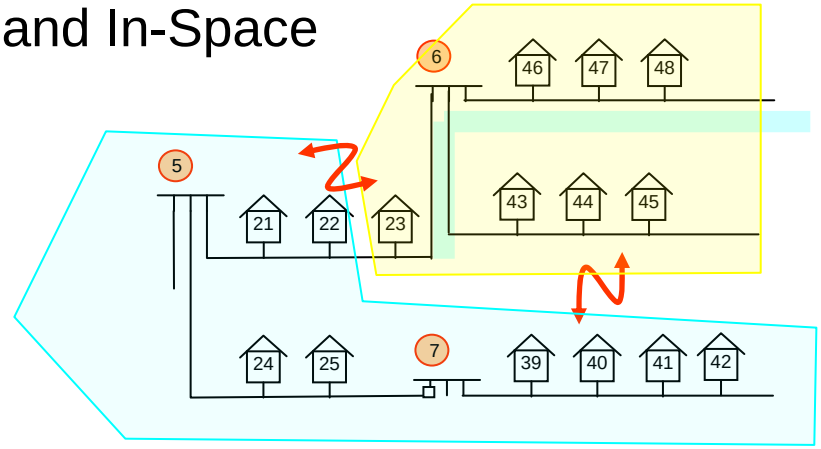


- LV: Low Voltage
- MV: Medium Voltage
- HV: High Voltage

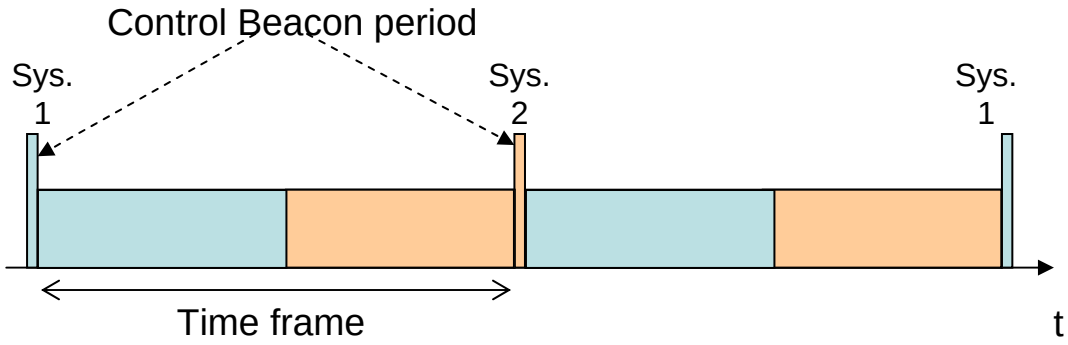
Source: OPERA

Transmission Capacity and Coexistence

- Interference: In-Line and In-Space



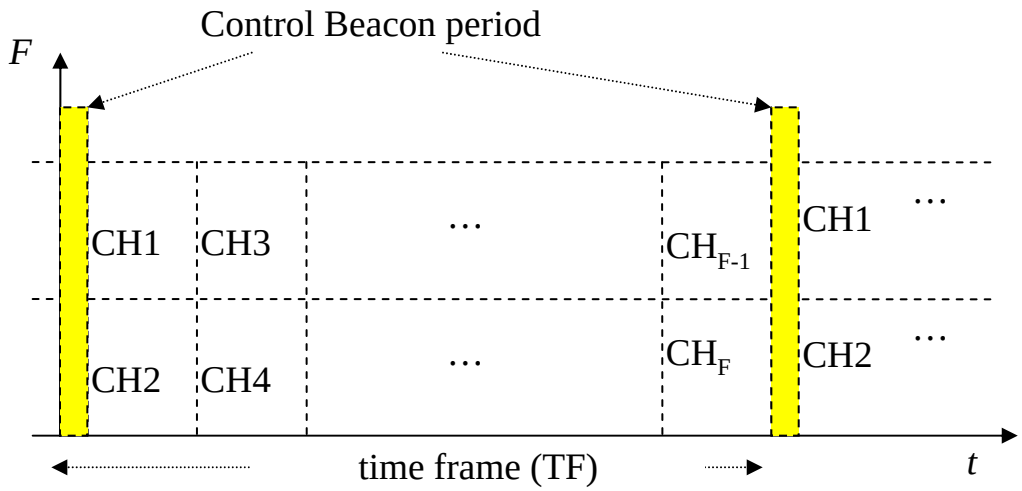
- The Inter Phy Protocol (IPP)*: Idear: Detection of the neighbor cells by listening to the beacon signal from the neighbors



* Specified in the IEEE P1901

Organization of Channels

- 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



Objectives

- 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:

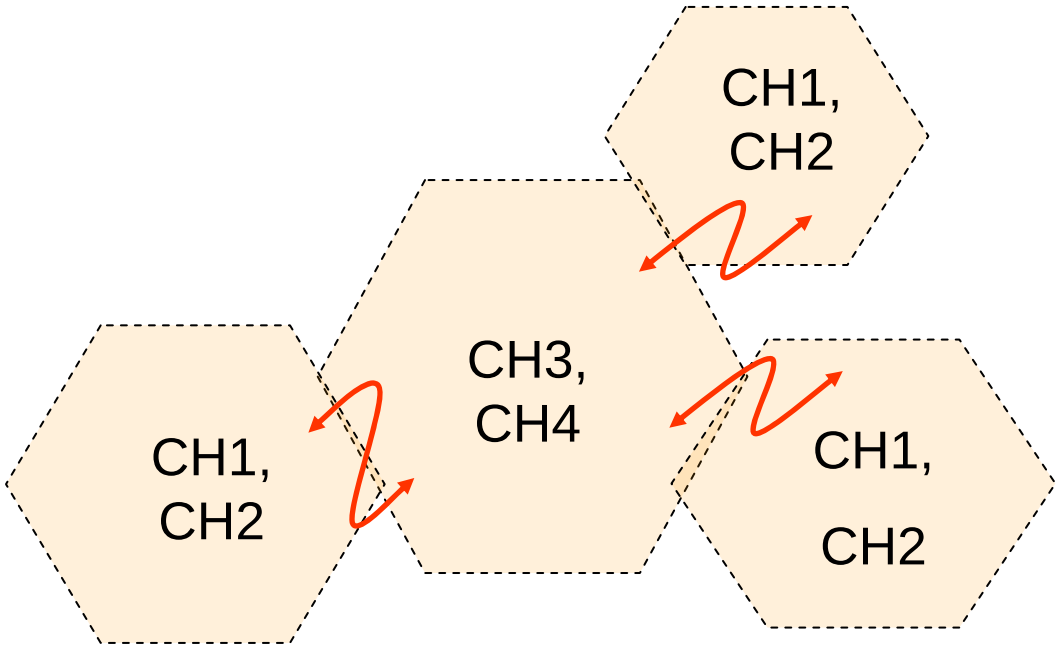
$$P_i = B_{Ci} / N_i$$

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

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

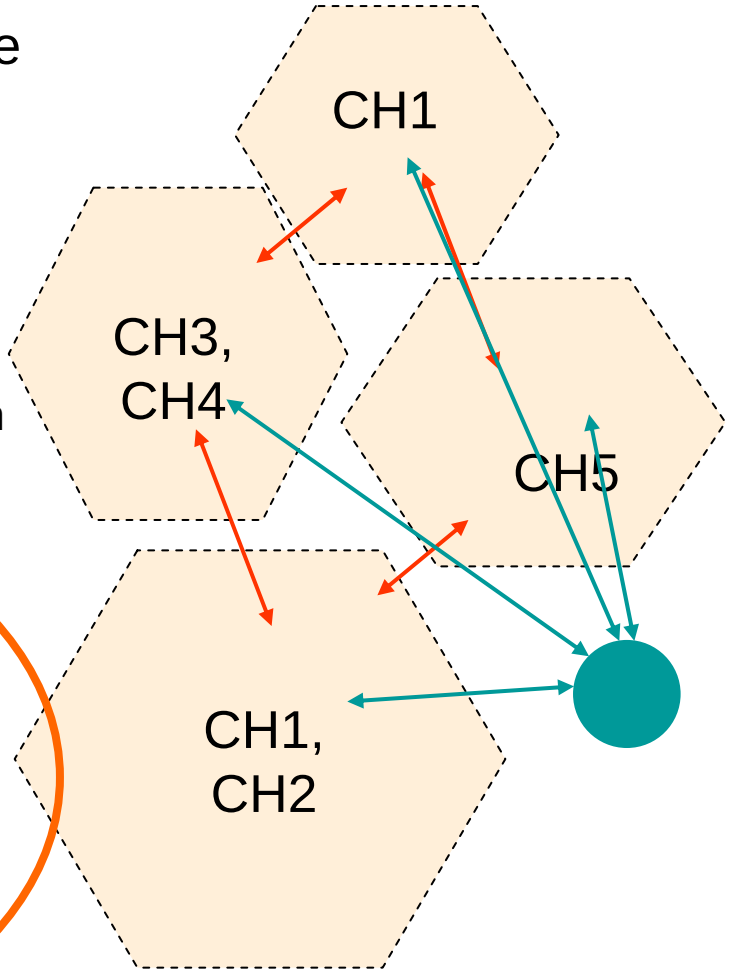
Sharing Transmission Capacity

- 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



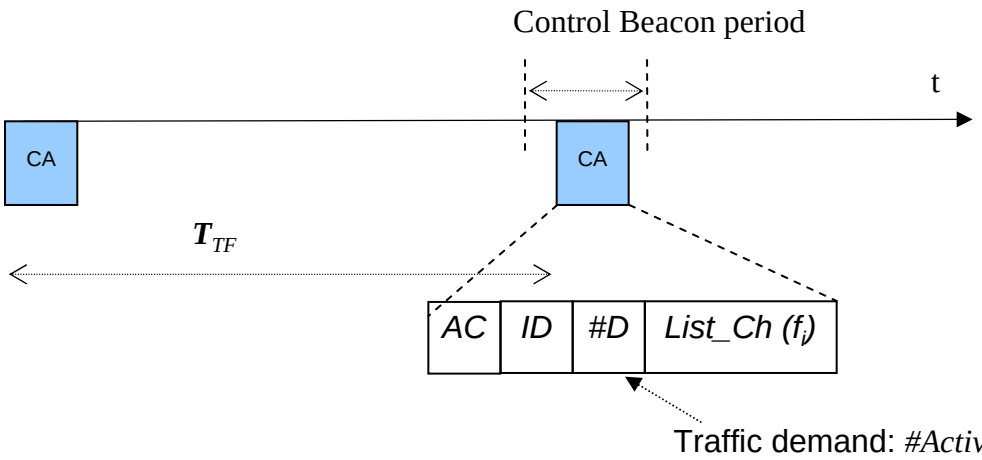
Sharing Transmission Capacity (2)

- 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



Between Cells Communication Issues

- 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

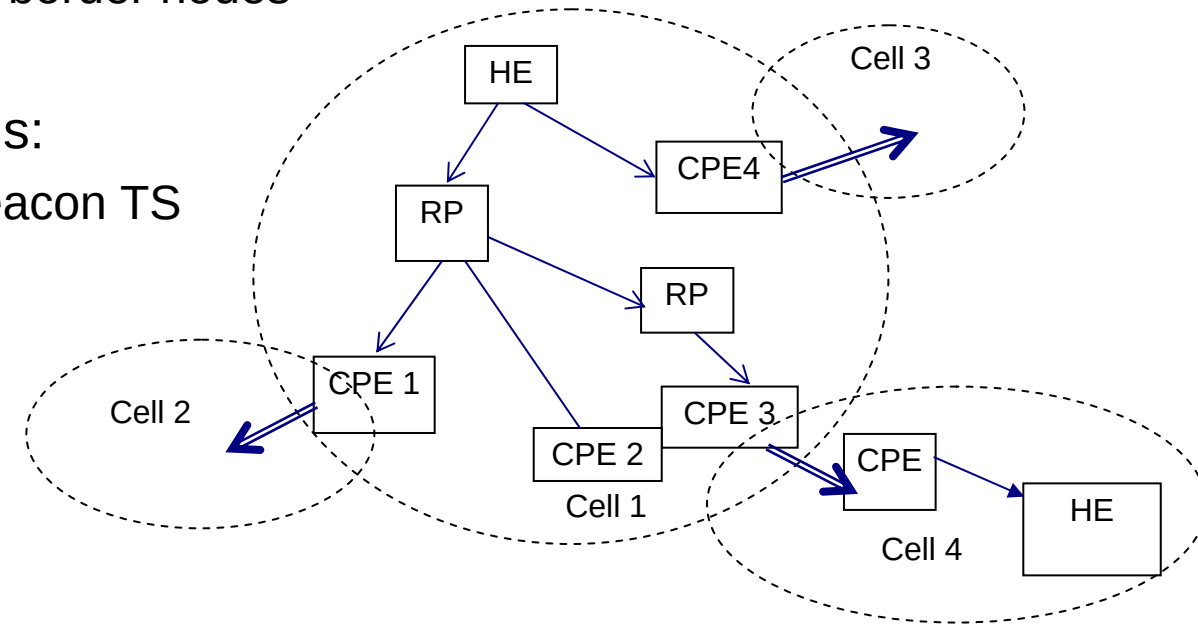


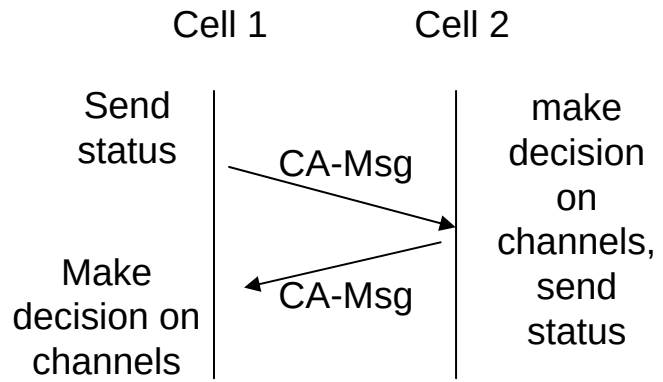
AC: 1 Byte: Access or InHome
ID: 6 Byte: Address of the Master
#D: 1 Byte: , of active users
List_Ch(f_i): 2 bit for a channel
• 0: Channel is free
• 1: occupied by this cell
• 2: used by one neighbor cell
• 3: used by more than one neighbor cells

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

Communication Between Cells

- 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

Between Cells Communication Issues

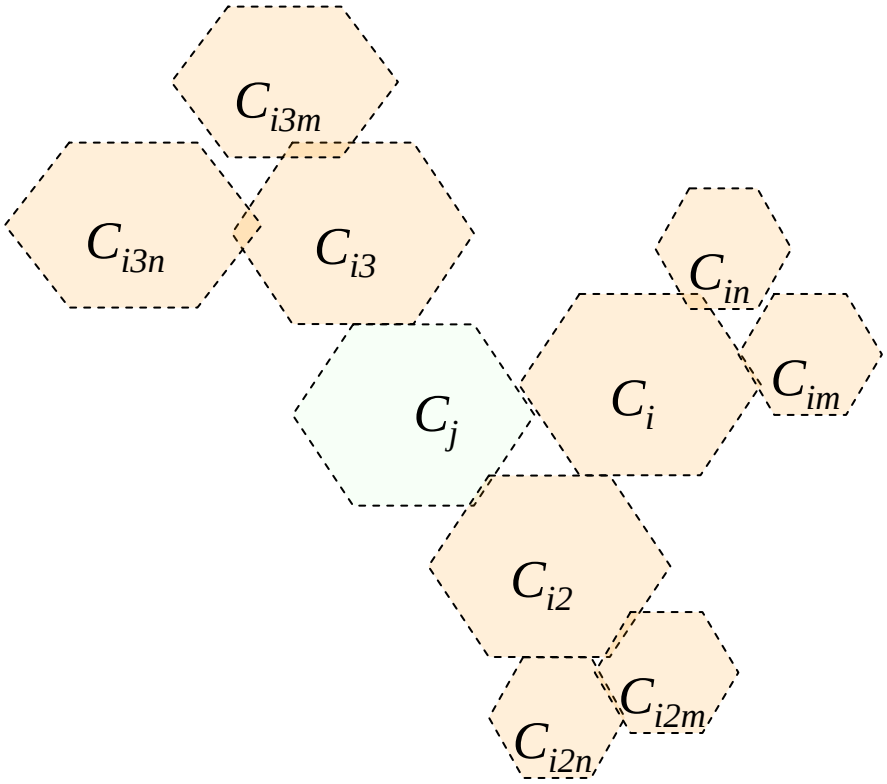
- Probability to select a slot

(1 neighbor has H_i neighbors)

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

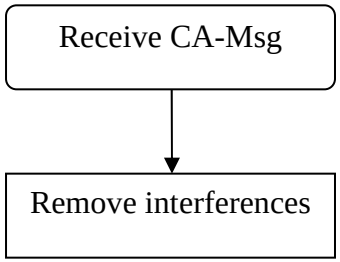
- Probability to select a slot

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



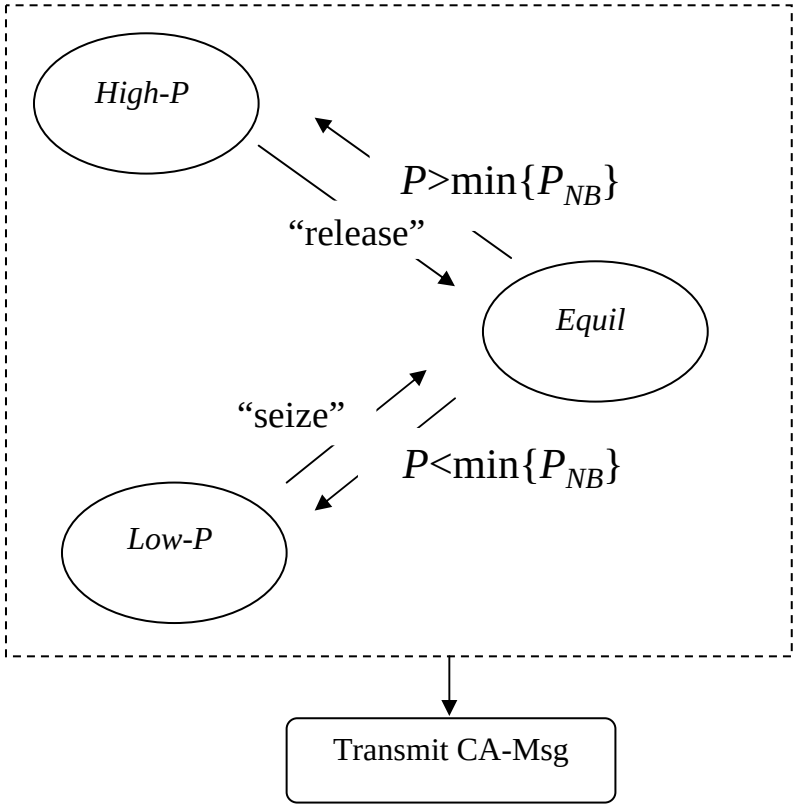
Master Station: Decision on Channels

- Two objectives⇒Two procedures
  - Maximizing the number of channels allocated in all cells
    ⇒ Seize Channels



  - Same P – fairness (in different cells)
    ⇒ 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

An Example with the Procedures

- Channel seize
  - Combine channel in use by its neighbors
  - seize the “unused” channel
- Channel release
  - Compare channel/demand with neighbor (Cj) which has lowest channel/demand
  - Find number of channels has to be released: can be obtained by Cj
    - 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

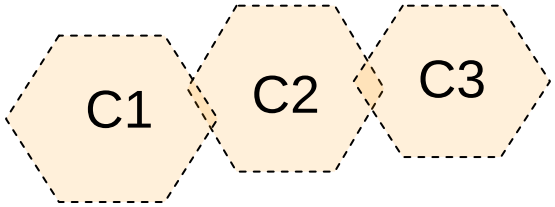
C1

	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						



Evaluation Metrics

Given: Set of channels: **F**=$\{1,..,F\}$, Set of cells: **C**=$\{1,..,S\}$, 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): $Ch_{Ci}=(a_{i,1}, a_{i,2}, a_{i,3}, \ldots a_{i,F})$

  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

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

- Fairness index:
  - $1/S \le F_{All} \le 1$
  - 1: perfect, greater is better

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

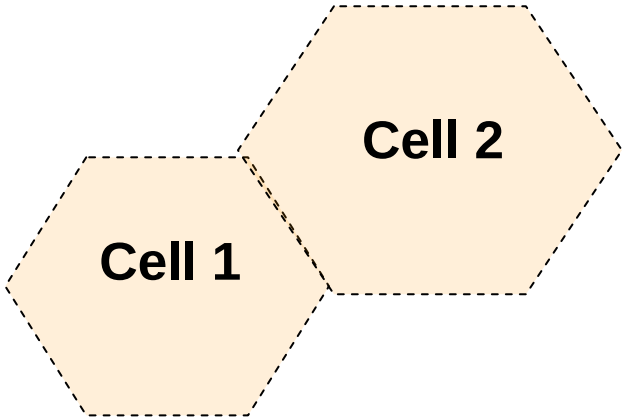
- Interferences

$$I_{All} = \sum_{i=1}^{S}\sum_{f=1}^{F} a_{i,f} \bigvee_{\substack{j=1 \\ j\neq i}}^{S} (i_{i,j} \cdot a_{j,f})$$

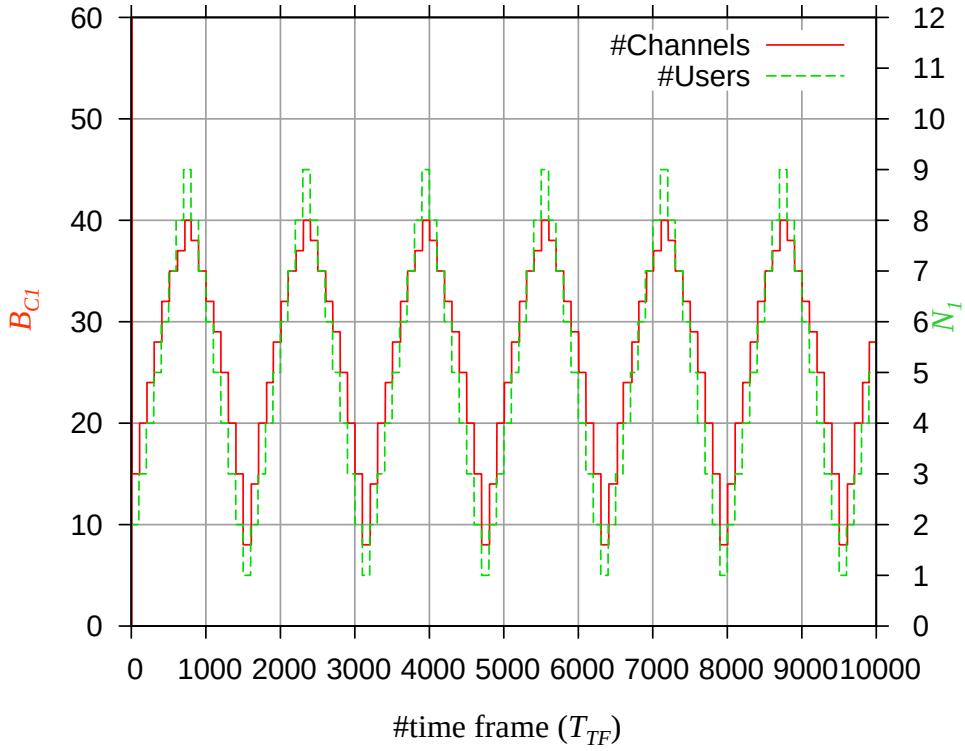
Small Network for Analysis

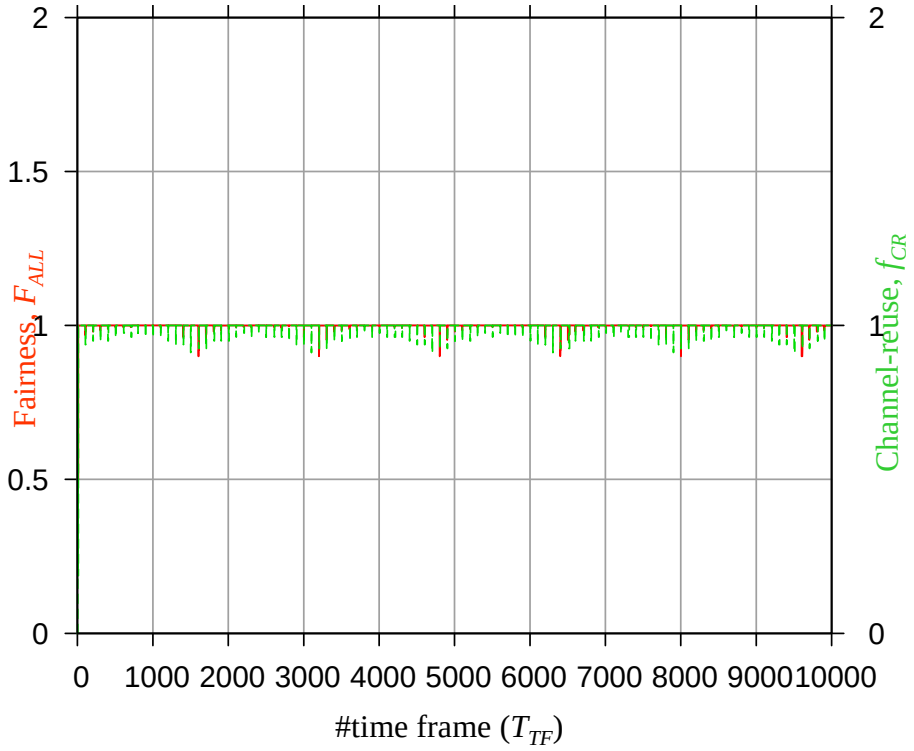
- Two cells (C_i=2), are neighbors ($i_{i,j}$=1)
- F=80

- 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
- $p_1^{send} = p_2^{send} = 0.5$



Small Network for Analysis





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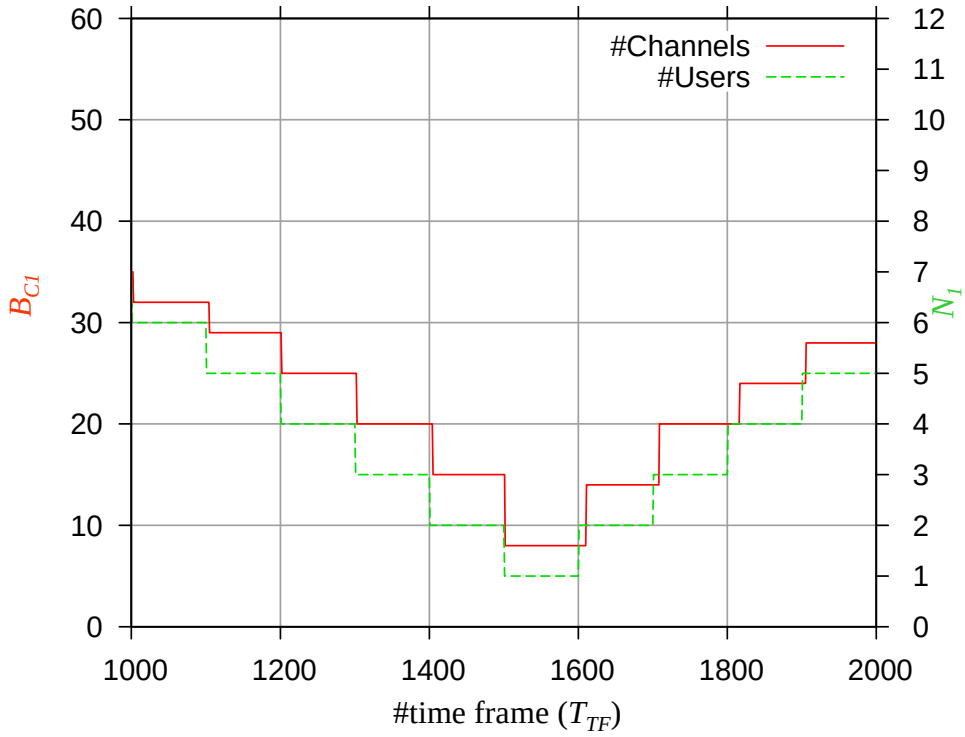
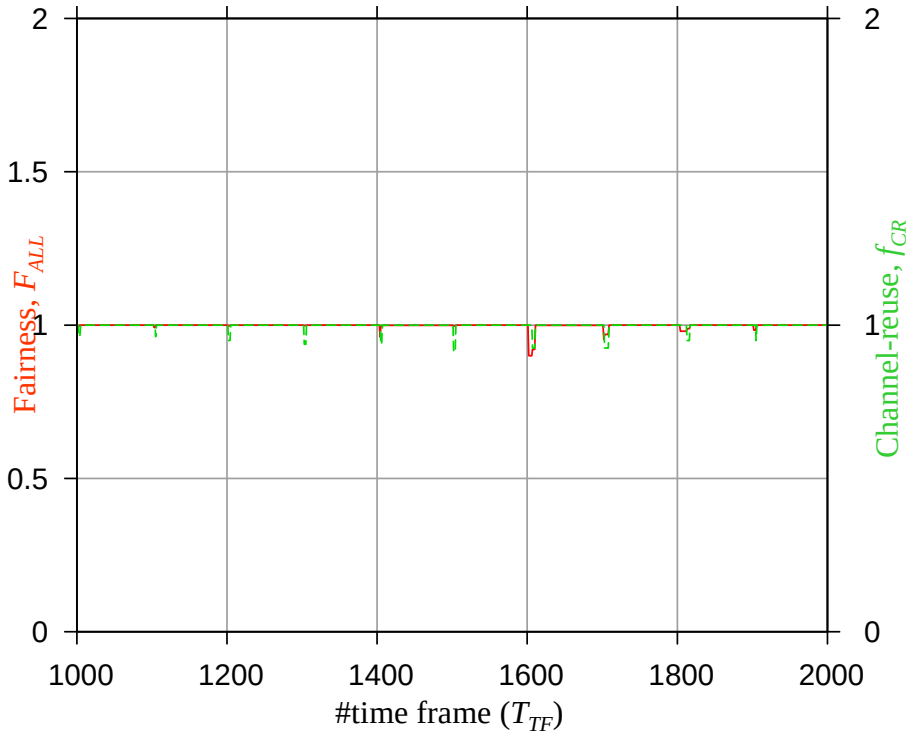
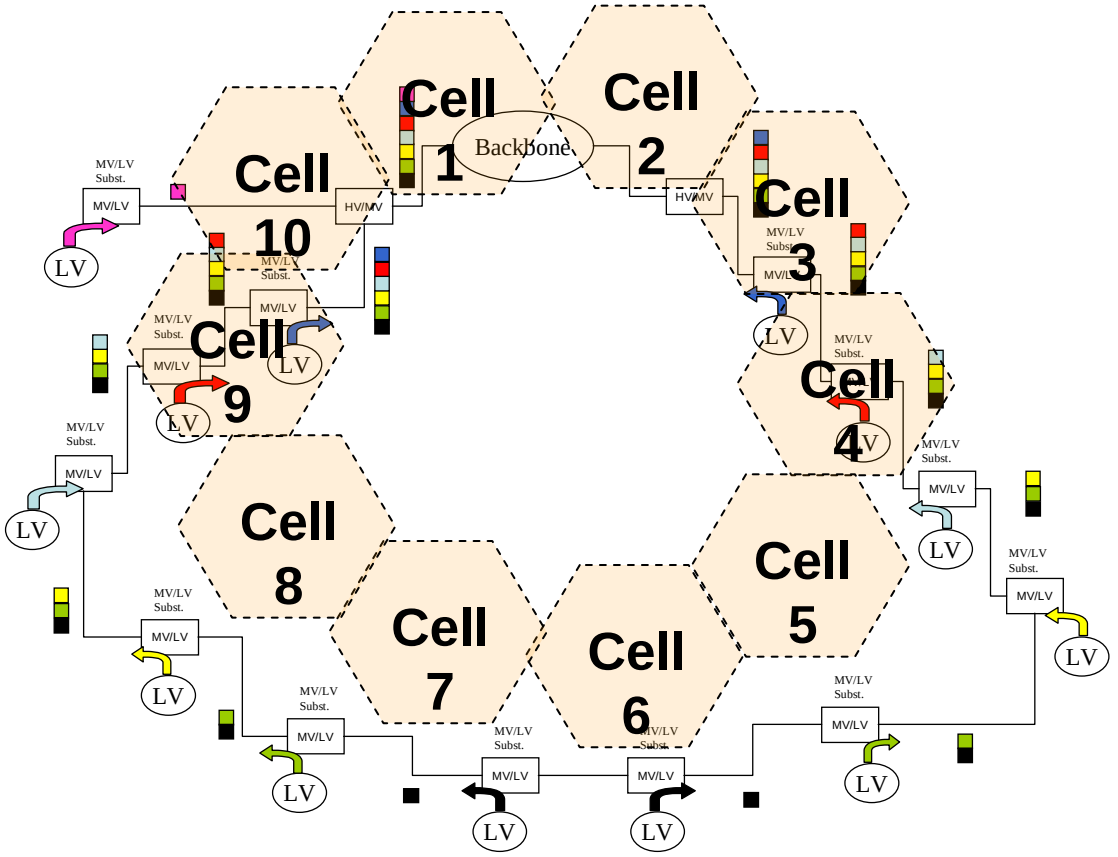




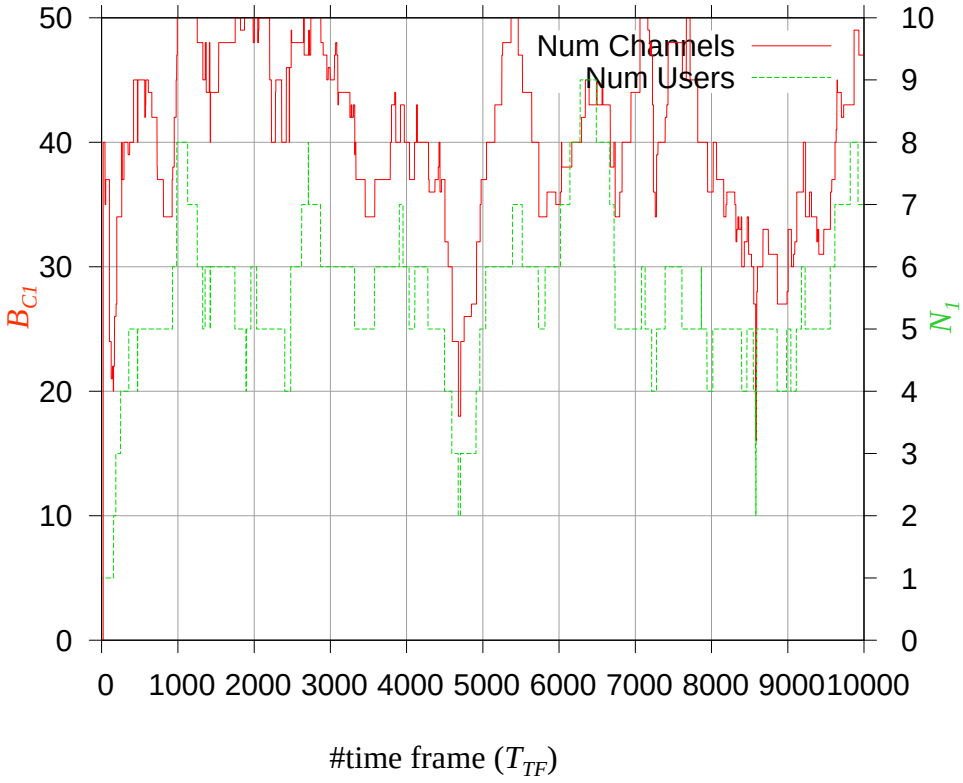
Example Network

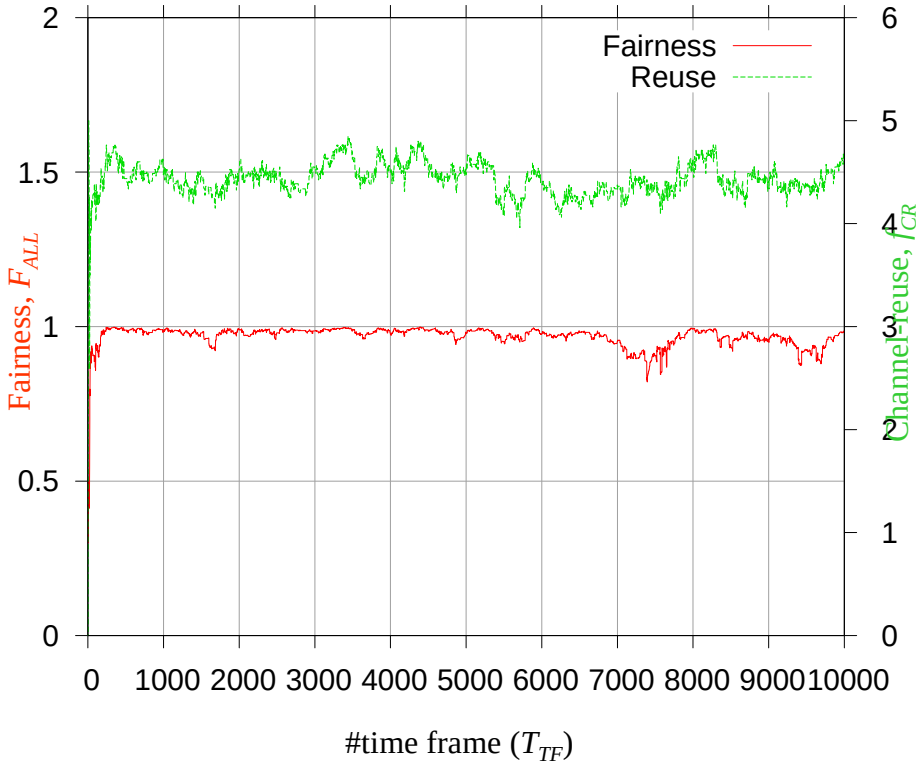
- Ring of 10 cells
- Interferences with two neighbors
- 9 users/cell with on/off model:
- On and Off phases Geo
  - $\mathrm{E}\{T_{ON}\}$= 100TF
  - $\mathrm{E}\{T_{OFF}\}$= 100TF



Simulation Results

Cell1





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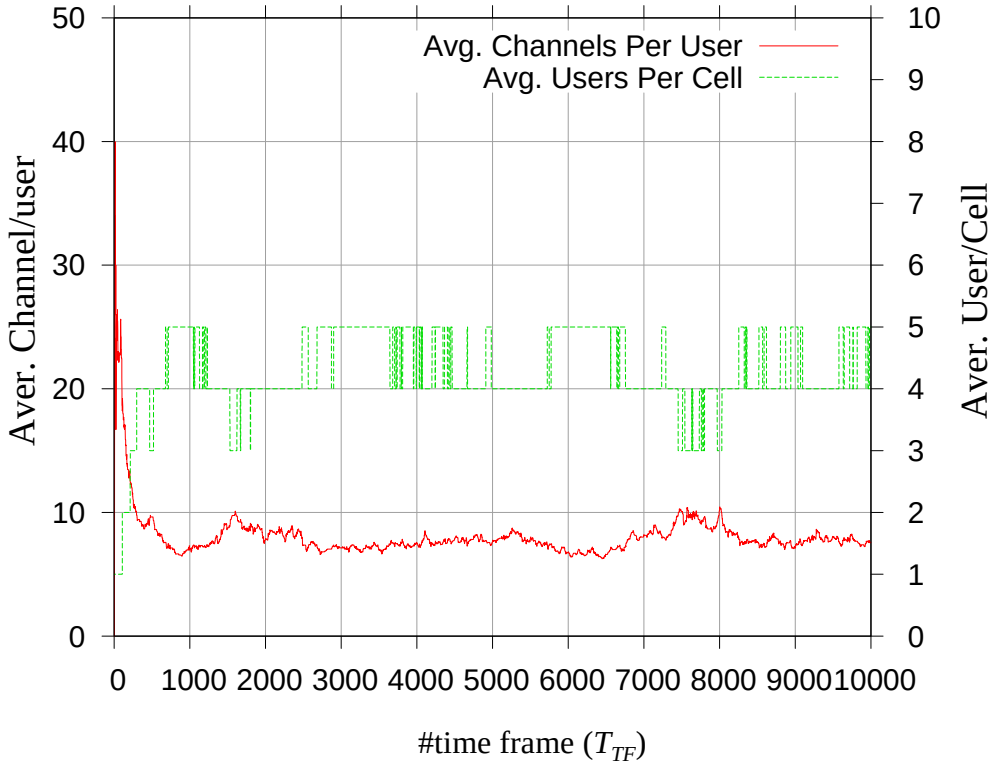

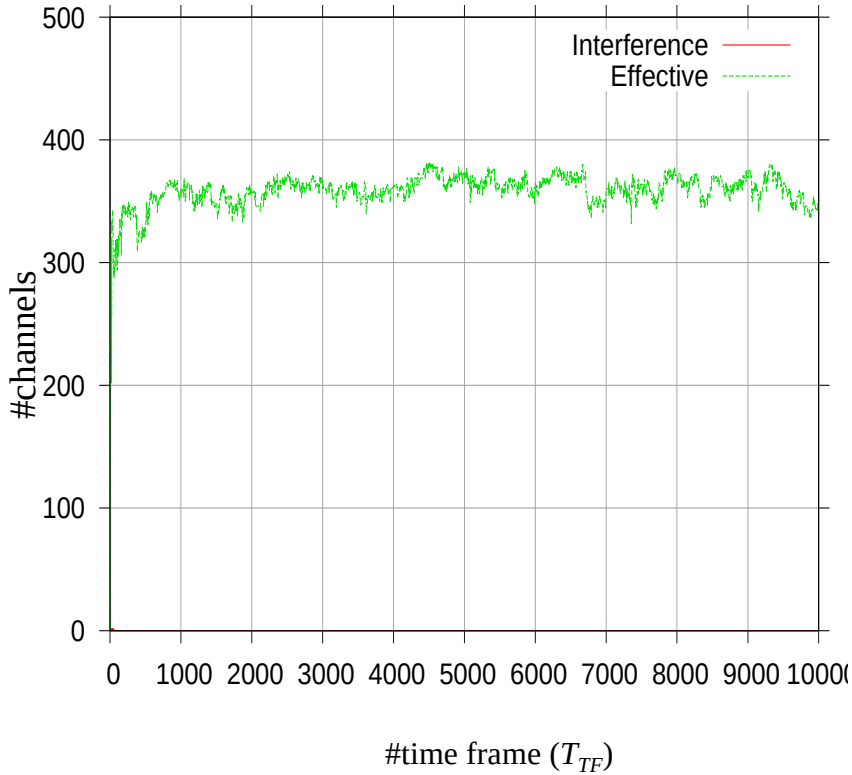

E.g. If a channel can be used to transmit 1Mbps
→ Average speed/user ≈8.2Mbps

#effective channels = #allocated channels - #interfering channels

Conclusions

- 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.