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Distributed Runtime Synchronization for 5G small cells

Gilberto Berardinelli **(presenter),** Fernando M.L. Tavares, Nurul H. Mahmood, Oscar Tonelli, Andrea F.Cattoni, Troels B. Sørensen, Preben Mogensen

Department of Electronic Systems, Radio Access Technology Section

Aalborg University, Denmark

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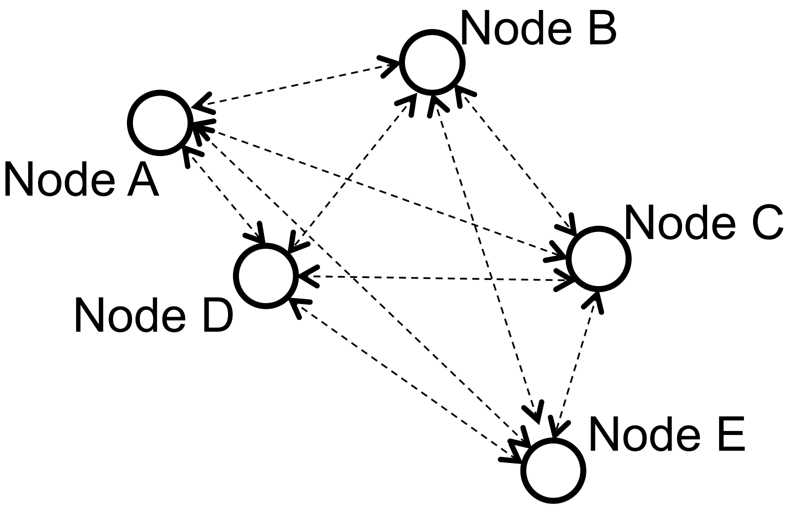
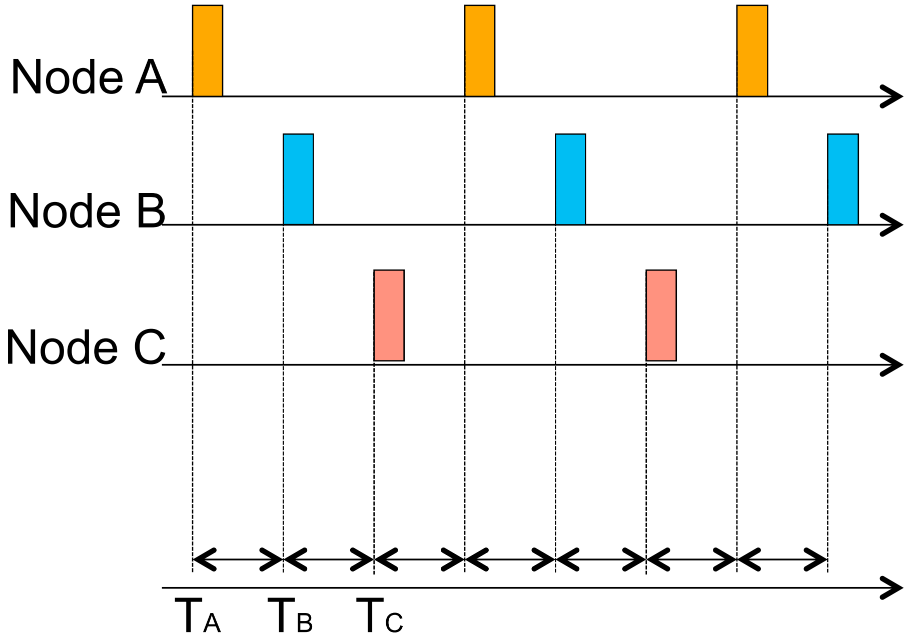
Introduction

- A massive deployment of small cells (e.g. femtocells) is foreseen as a solution for coping with the exponential increase of the indoor data traffic demand.
- A novel 5G radio standard has to be designed for circunventing the limitations of the existing standards in such dense scenarios.
- A novel 5G will feature:
  - → OFDM modulation
  - → multiantenna technology (MIMO)
  - → Time Division Duplex (TDD) mode
  - → advanced interference coordination/suppression capabilities
- Network Synchronization is foreseen as a key enabler for enhanced local area technology.
- Unfortunately, the GPS reference fails in indoor due to penetration losses
- **In this study, we study the feasibility of distributed synchronization for a 5G local area system.**

Distributed synchronization

How can multiple nodes share the same timeline?



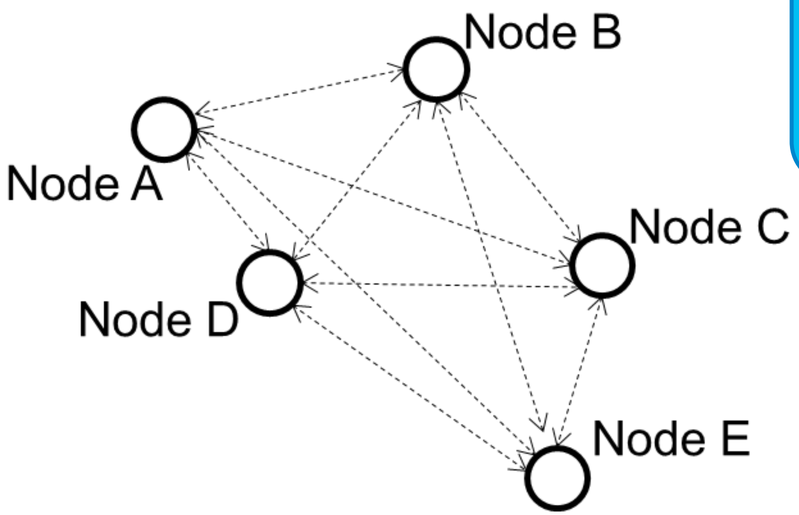


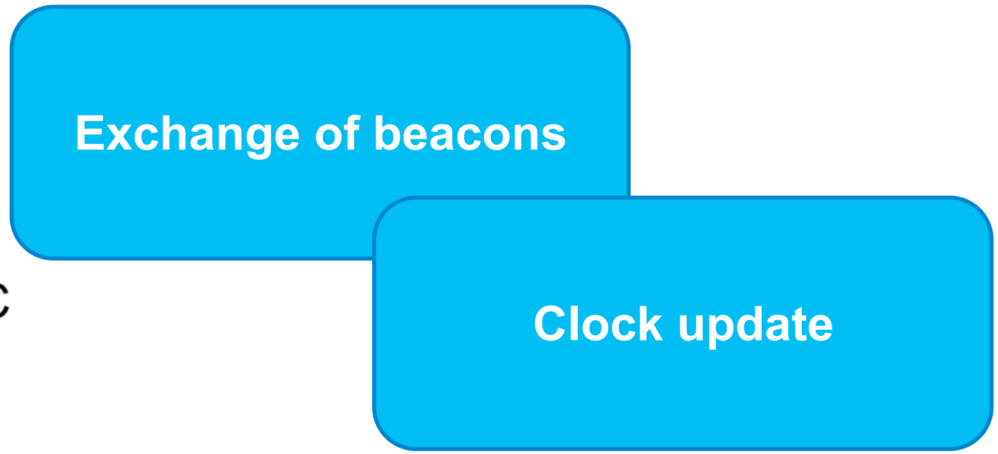
We distinguish between:

- **Initial synchronization**: how to make all the nodes in the network fire at the same instant (or with a predefined offset)
- **Runtime synchronization**: how the maintain the synchronization among the nodes despite of the inaccuracies of the hardware clocks

Runtime Synchronization

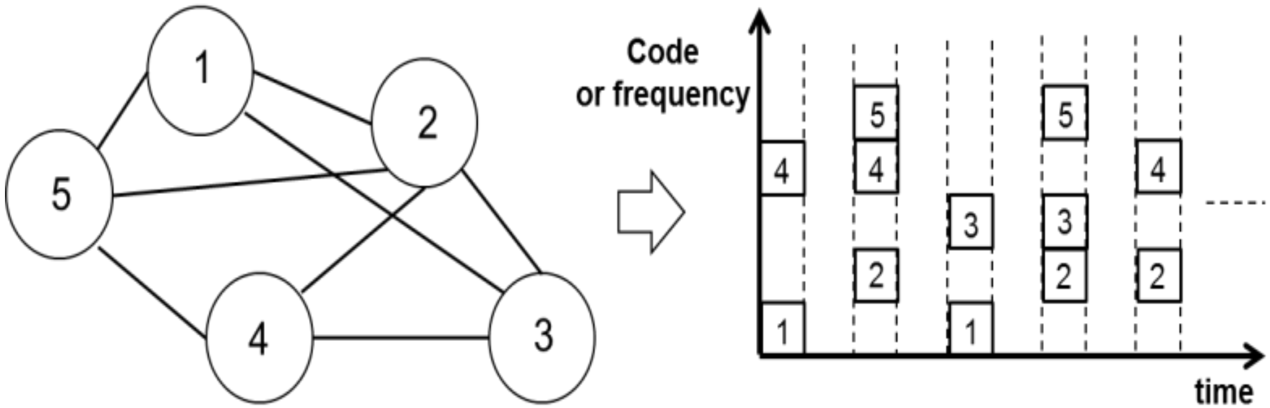
- Let us assume that a coarse initial synchronization is already achieved and we focus on the **runtime synchronization** problem, i.e. how to keep time alignment among the network nodes despite of the different clock functions.
- For inter-BS communication without any hierarchy, clock correction procedures are based on the exchange of beacon messages among the BSs, which react by updating their clock functions according to a predefined update criterion.





Beacons' scheduling

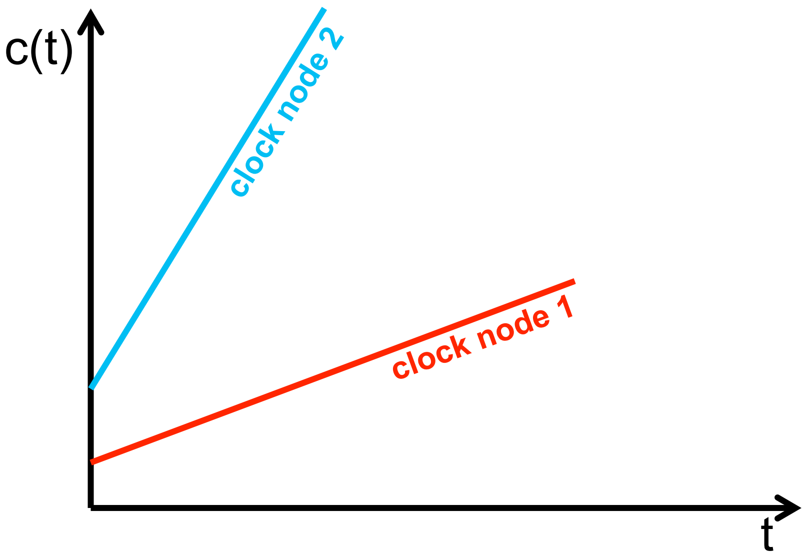
- The half-duplex constraint due to the TDD mode (i.e., each node can only transmit or receive at a time) raises the issue of a proper scheduling of the beacons.
- Let us assume that the beacons of multiple nodes can be multiplexed within the same time symbol, for instance in different frequency blocks or by using orthogonal codes.
- By following a simple **random scheduling criterion**, each node can decide at each inter-beacon time whether to transmit its beacon with a certain probability *p* or to receive the beacons eventually sent by the other nodes.



Clock update

- Nowadays commercial clocks have linear transfer function within a large time window (minutes)

  c(t)=at+b (a=1, b=0 ideal clock)



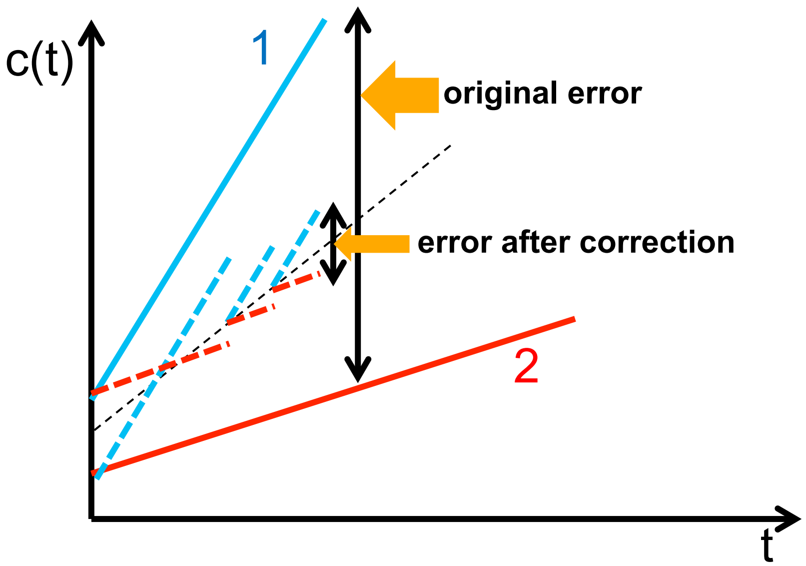
Clocks with different slopes will diverge fast
In case a correction measure is not applied
(e.g., clocks with 1PPM accuracy
may diverge up to 2 us in 1 second)

- How to correct the clock functions in order to limit their divergence?
  - Additive term
  - Multiplicative term

Clock update

Correction with additive term

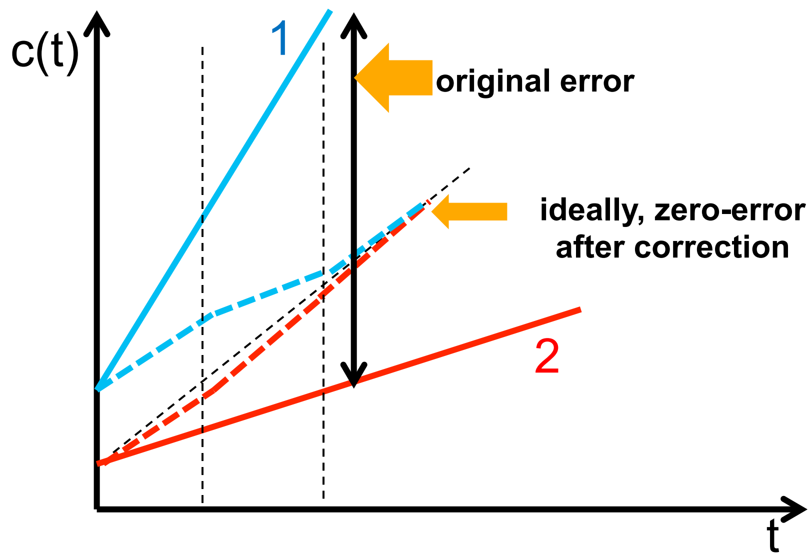
$c_i(t)=a_it+b_i+q_i$ correction term



Correction with multiplicative term

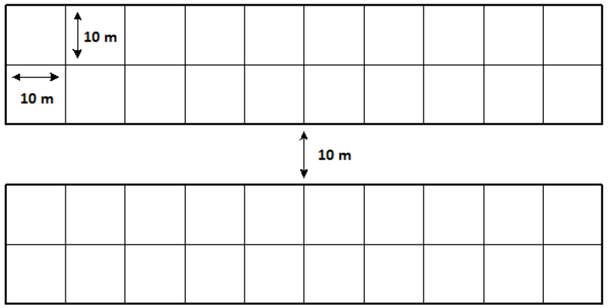
$c_i(t)=q_i(a_it+b_i)$

correction term



Performance evaluation

- Urban femtocells scenario with two stripes of apartments (3GPP)

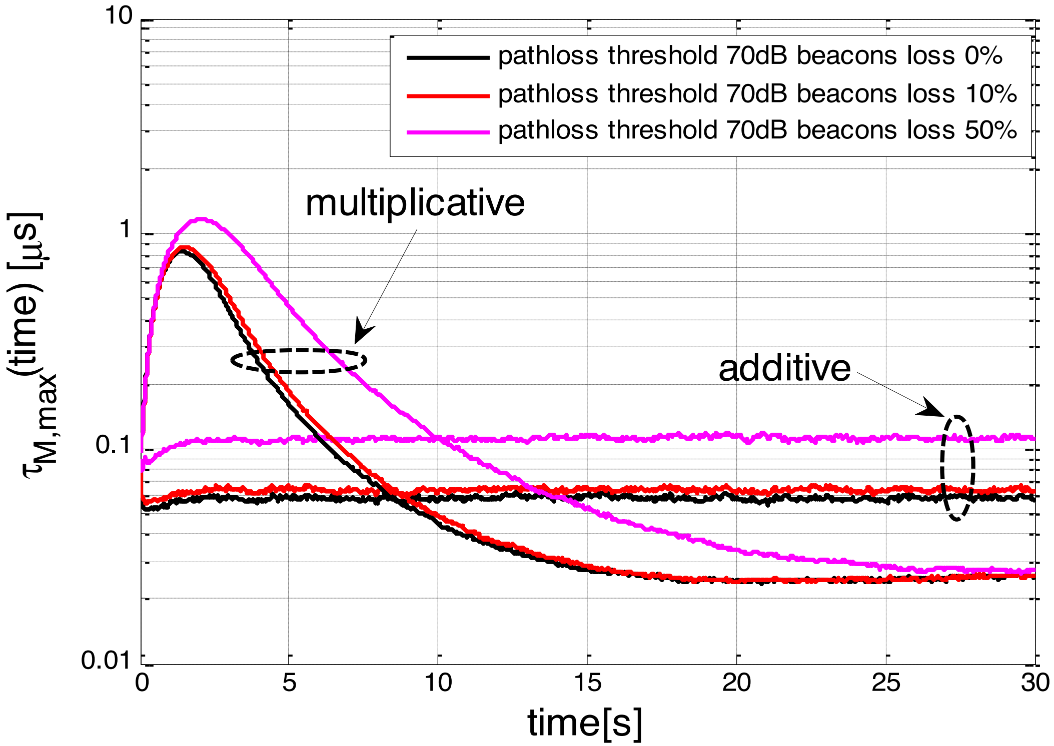


- Deployment ratios: 25%, 50%, 70%, 100%
- 500 drops
- Clock errors: within +/- 1 us/s
- Initial error: within +/- 0.1 us
- Inter-beacon time: 10ms
- Pathloss threshold: 70 dB
- Performance metric is the average maximum time misalignment

$$\tau_{M,i,j}(t) = \left| t_{air,i}(t) - t_{air,j}(t) \right| \qquad \tau_{M,max}(t) = \frac{1}{N_D} \sum_{r=1}^{N_D} \frac{1}{N_C} \sum_{u=1}^{N_C} \max_{i \in C_u, j \in V_i} \tau_{M,i,j}(t)$$

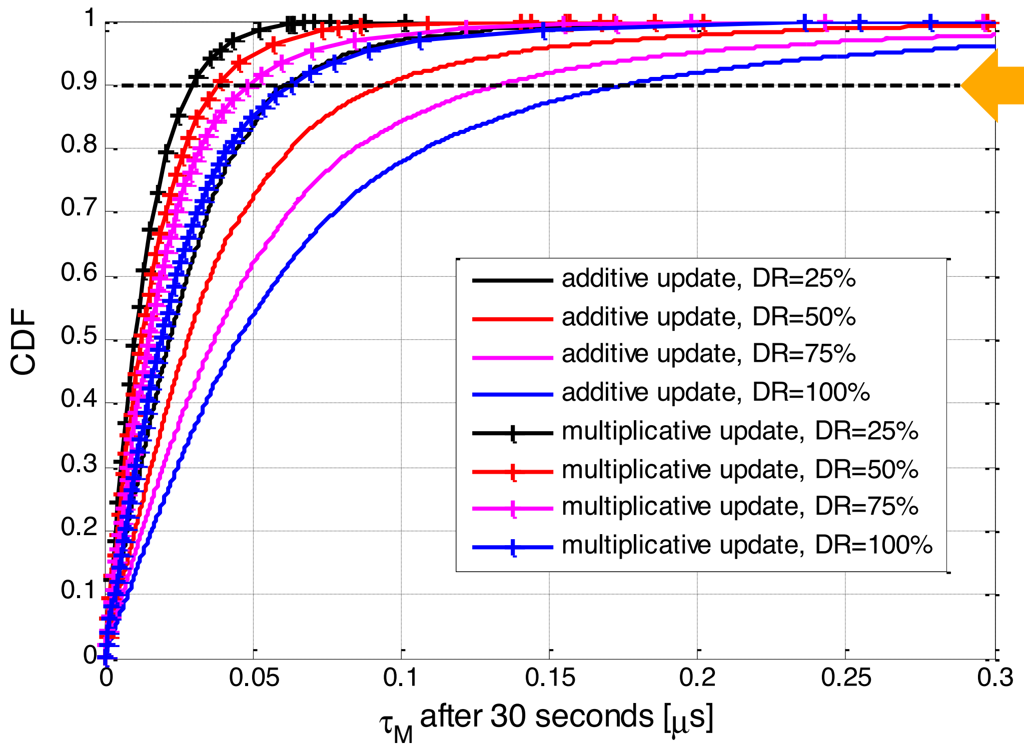
Performance evaluation

Average max misalignment – DR=50%



Performance evaluation

CDF of the time misalignment between pairs of nodes



Error below 200 ns in 90% Of the cases

Synchronization accuracy impact

How the synchronization accuracy impact the system design?
The achievable timing misalignment accuracy has an impact on the design of the Cyclic Prefix (CP) duration

$$T_{CP} > \tau_{\mathrm{M}} + \tau_{\mathrm{D}} + \tau_{\mathrm{HW}} + 2\tau_{\mathrm{P}}$$

τ_{D} delay spread
τ_{P} propagation delay
τ_{HW} response time of the hardware filters

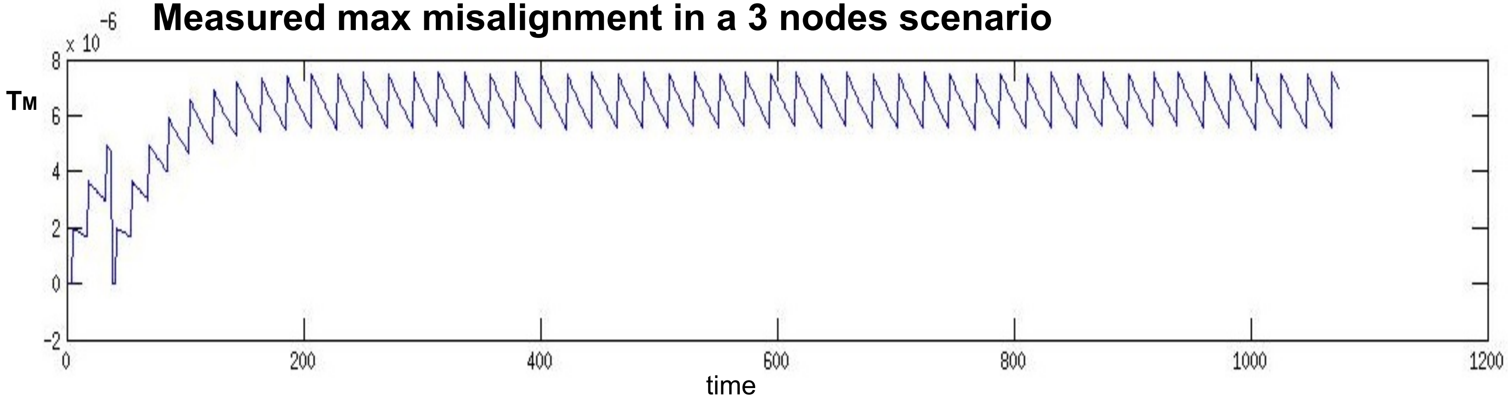
In local area:

τ_{D} = 100 ns
τ_{P} = 170 ns
τ_{HW} = 50 ns
τ_{M} = 200 ns

$$T_{CP} > 0{,}69\ \mu s$$

Conclusions and future work

- Clock correction based on an additive term suffers from an error floor.
- Clock correction based on multiplicative term suffers from an initial high time divergence, but shows a significantly lower error floor that additive approach.
- In the case of additive term correction, non-idealities such as beacon losses increase the error floor, while in the case of multiplicative term correction, they only increase the convergence time.
- **We are currently implementing with the ASGARD platform a testbed for distributed synchronization**



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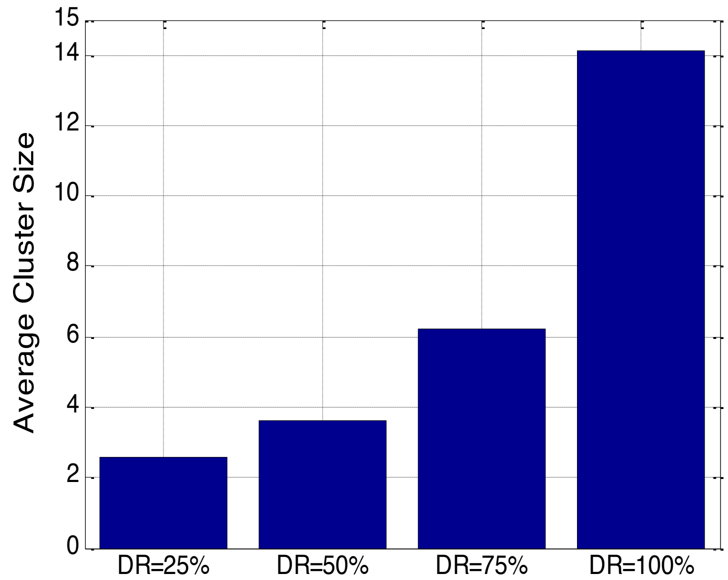
THANKS FOR YOUR ATTENTION!

Any questions?

Backup

Performance evaluation

Average cluster size (pathloss threshold 70 dB)



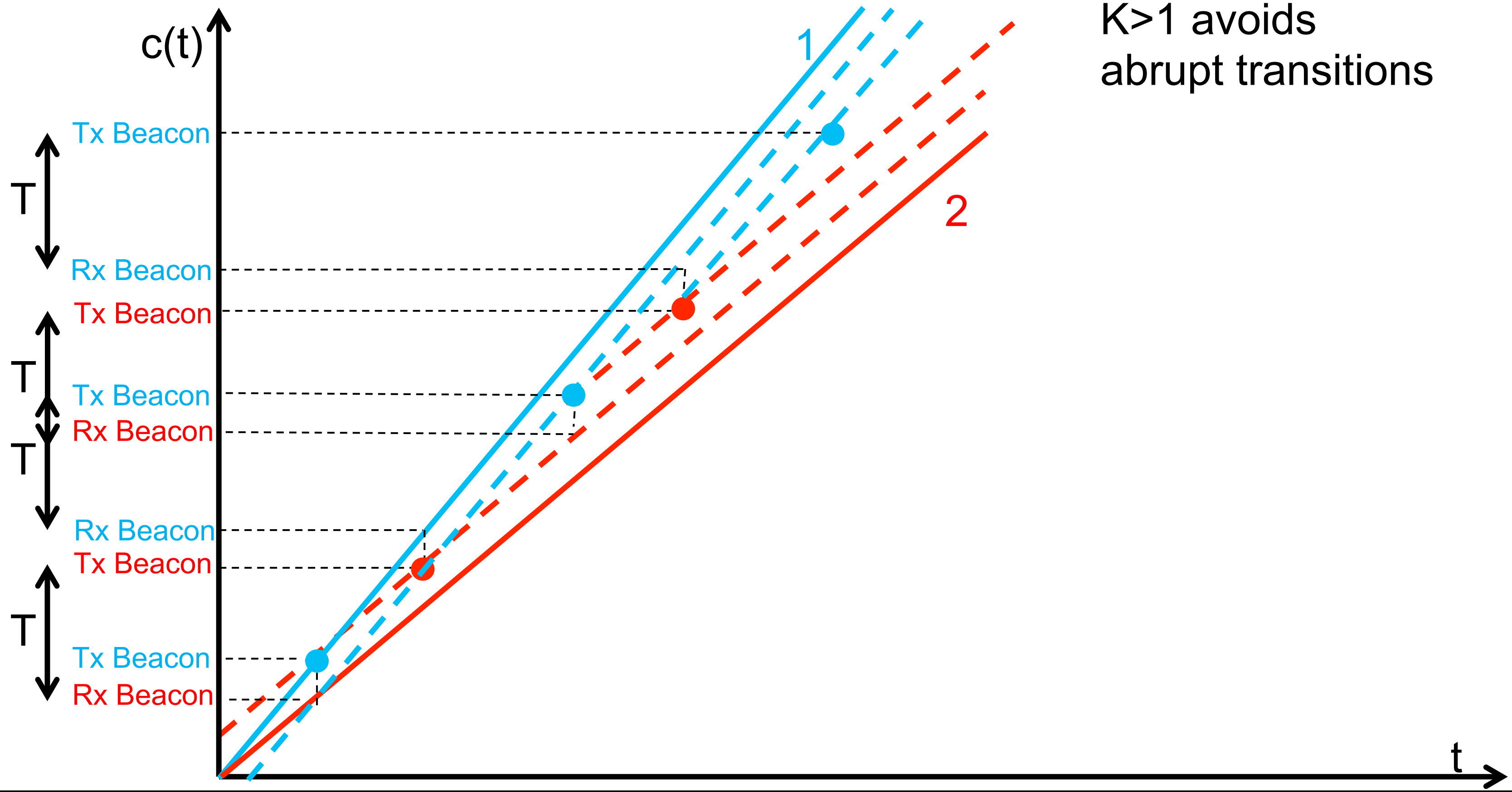
(Two nodes may belong to the same cluster even in case their pahloss relation is higher than 70 dB; this is because they may be connected to a common tree of neighbors)

Clock correction – additive term

- Upon reception of a beacon, the *i*-th node updates its local timing as follows:

$$c_i(t_Z) = c_i(t_{Z-1}) + T + \boxed{\frac{r_i(t_{Z-1}) - c_i(t_{Z-1})}{K}}$$

correction term



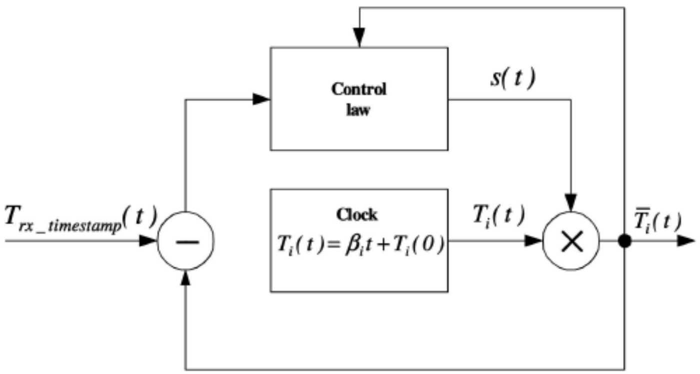
K>1 avoids abrupt transitions

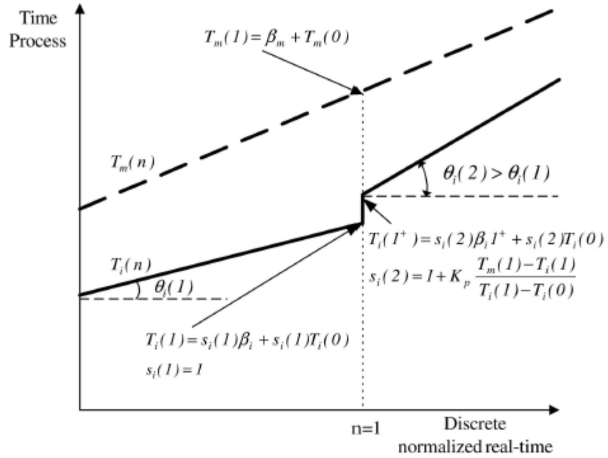
Clock correction – multiplicative term

The i-th node corrects its clock as follows:

with $$\tilde{c}_i(t_Z) = s_i(t_Z)c_i(t_Z)$$

$$s_i(t_Z) \;=\; s_i(t_{Z-1}) + k\frac{r_i(t_Z) - c_i(t_Z)}{r_i(t_Z) + B}$$





It is designed such that

$$\lim_{t\to\infty} s_i(t)c_i(t) = q \;\; \forall i$$

[1] C. H. Rentel et al. "A mutual network synchronization method for wireless ad hoc and sensor Networks"