

Distributed Frequency Locked Loops for Wireless Sensor Networks

Nicola Varanese, O. Simeone, Y. Bar-Ness, U. Spagnolini

New Jersey Institute of Technology / Politecnico di Milano

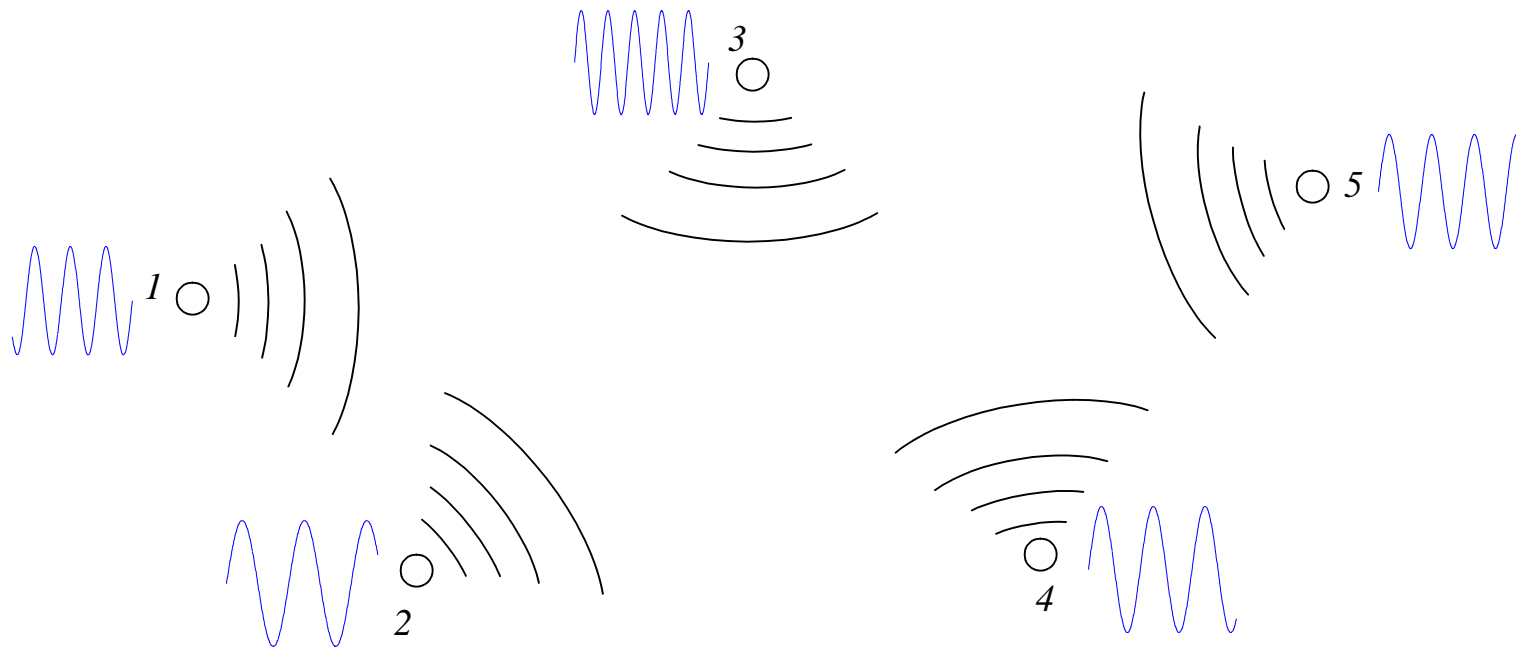


Motivation

- ❑ Consider packet-based communication in a wireless network (e.g., Wireless Sensor Network)
- ❑ Symbol timing and frequency synchronization enable cooperative transmissions without complex receiver structures
- ❑ **No master reference !**
- ❑ Focus on carrier frequency synchronization among distributed wireless nodes
 - carrier phase offsets can be easily compensated (e.g., by the use of differential communication schemes)

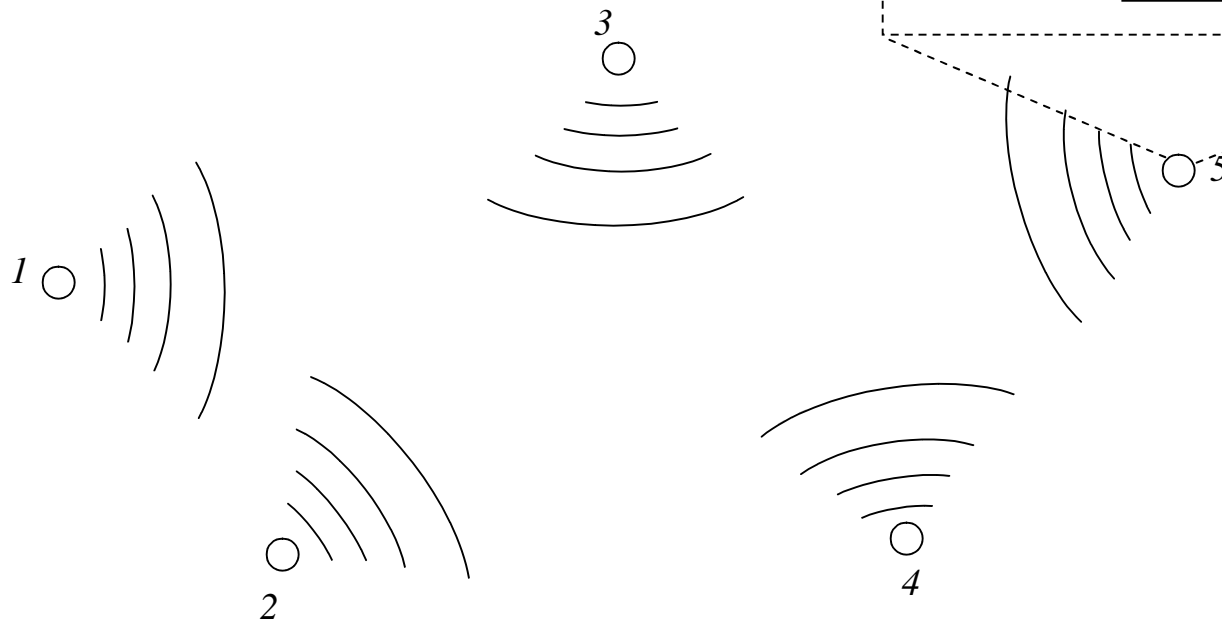
A frequency asynchronous network

- Every node has an independent local carrier frequency reference:
 - Channel Tracking
 - Synchronization



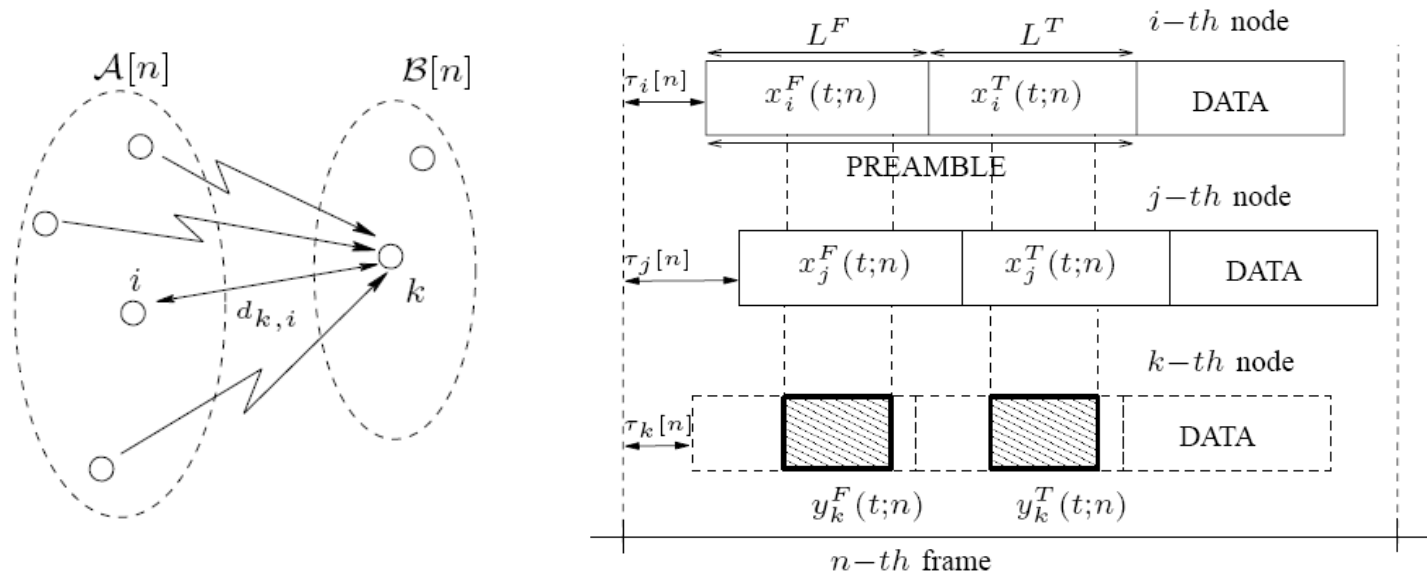
Distributed Digital Locked Loops

- Every node runs a Digital Locked Loop
- The carrier frequency is the locking parameter



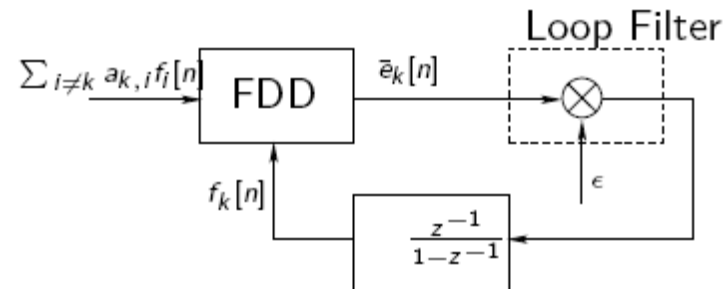
System model

- ❑ Half duplex constraint
- ❑ Time-slotted access; pre-established frame sync
- ❑ Training-aided symbol timing and carrier frequency sync
- ❑ Block fading



Distributed Frequency Locked Loops

□ Idealized model



□ Local frequency update

$$f_k[n+1] = f_k[n] + \epsilon \underbrace{\frac{1}{\sum_{i \neq k} a_{k,i}} \sum_{i \neq k} a_{k,i} (f_i[n] - f_k[n])}_{\bar{e}_k[n]}$$

□ How to design the Frequency Difference Detector ?

FDD design

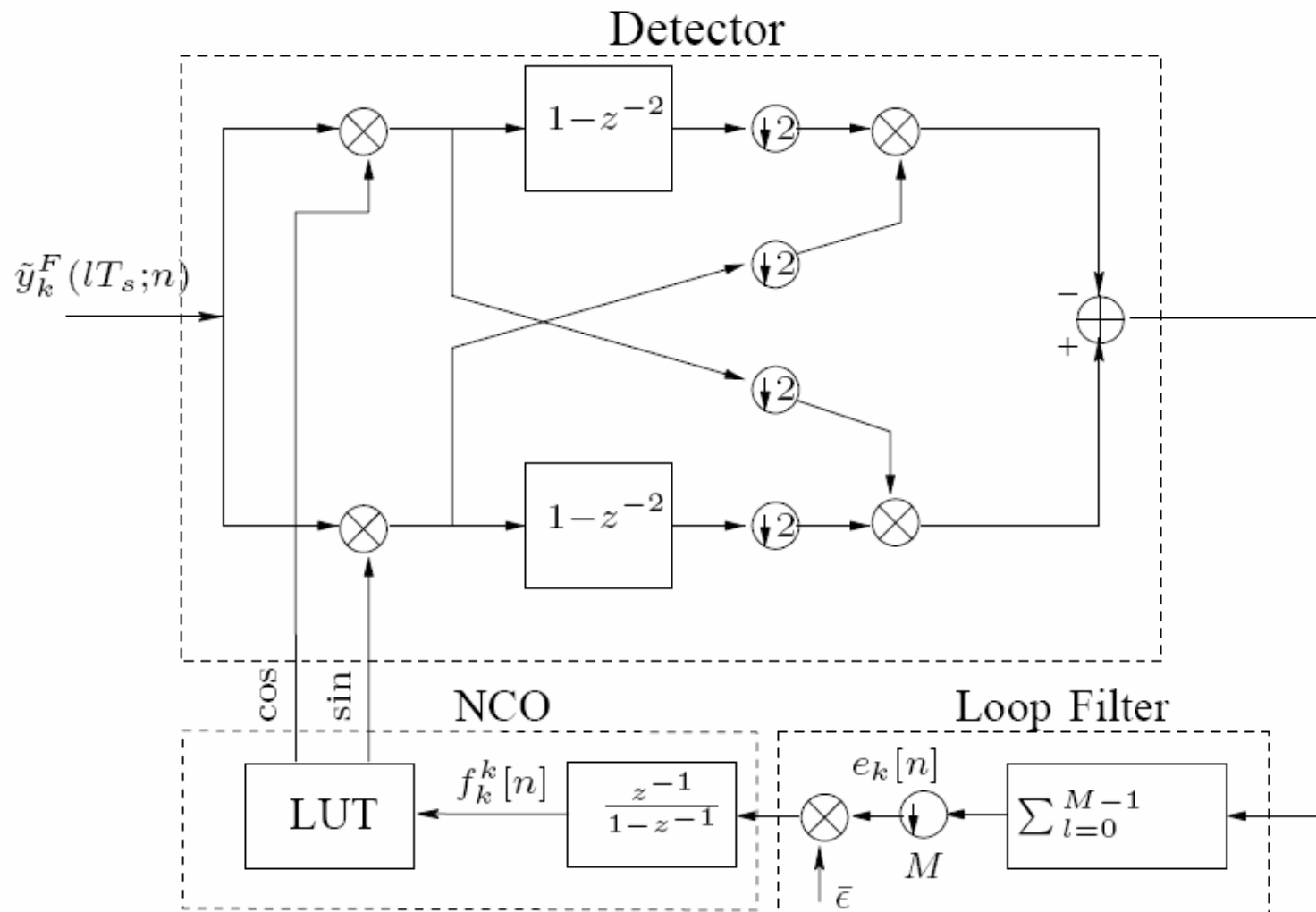
- If the observation interval is large (PAM signaling)

$$\bar{e}_k[n] = \frac{\sum_{i \neq k} a_{k,i} (f_i[n] - f_k[n])}{\sum_{i \neq k} a_{k,i}} = \frac{\int_{-\infty}^{\infty} f \cdot |Y_k(f; n)|^2 df}{\int_{-\infty}^{\infty} |Y_k(f; n)|^2 df}$$

- Which can be approximated as

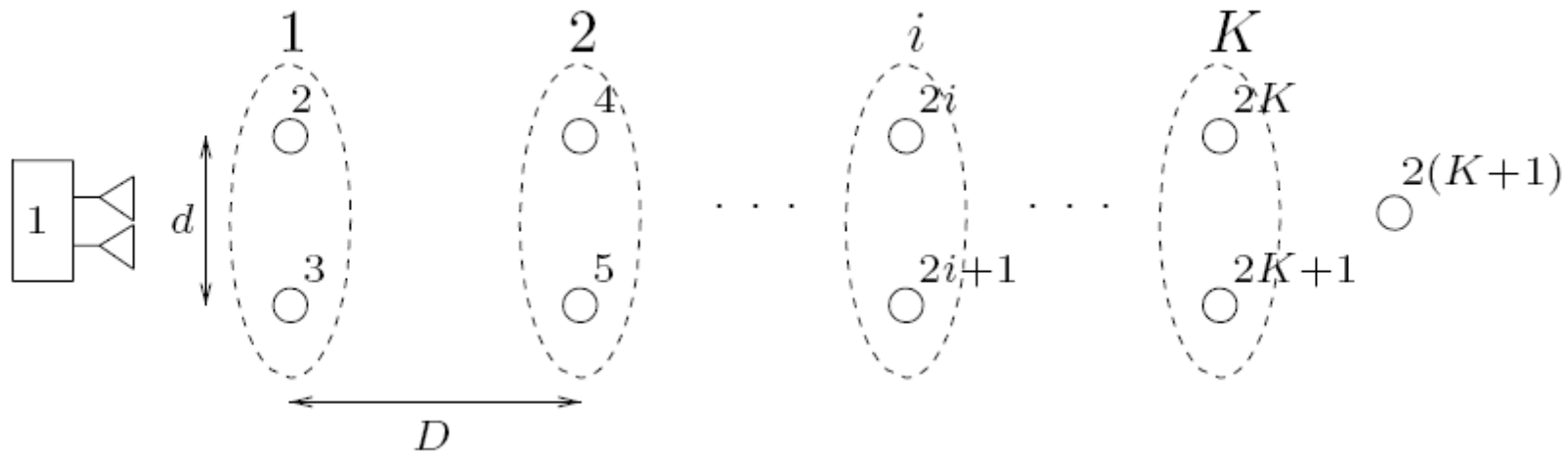
$$\bar{e}_k[n] \simeq \frac{1}{2\pi} \text{Im} \left\{ \sum_{m=0}^{\frac{L-3}{2}} y_k((2m+2)T_s; n) y_k^*((2m+1)T_s; n) + \right. \\ \left. - y_k(2mT_s; n) y_k^*((2m+1)T_s; n) \right\} \frac{1}{2T_s \sum_{m=0}^{\frac{L-3}{2}} |y_k((2m+1)T_s; n)|^2}$$

Digital Balanced Quadratic Correlator



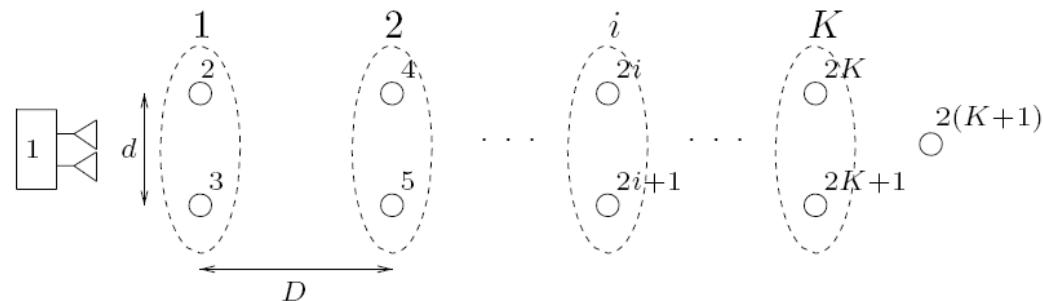
An application

- ❑ Multi-Hop Multi-Relay network
- ❑ Differential Alamouti ST code



- ❑ Sync schemes:
 - Open loop
 - Closed loop A
 - Closed loop B

An application



❑ **Open loop:**

- when a node decodes the data payload of the transmitted packet(s), $f_k[n]$ is computed based on the preamble signal(s)
- Memoryless

❑ **Closed loop A:**

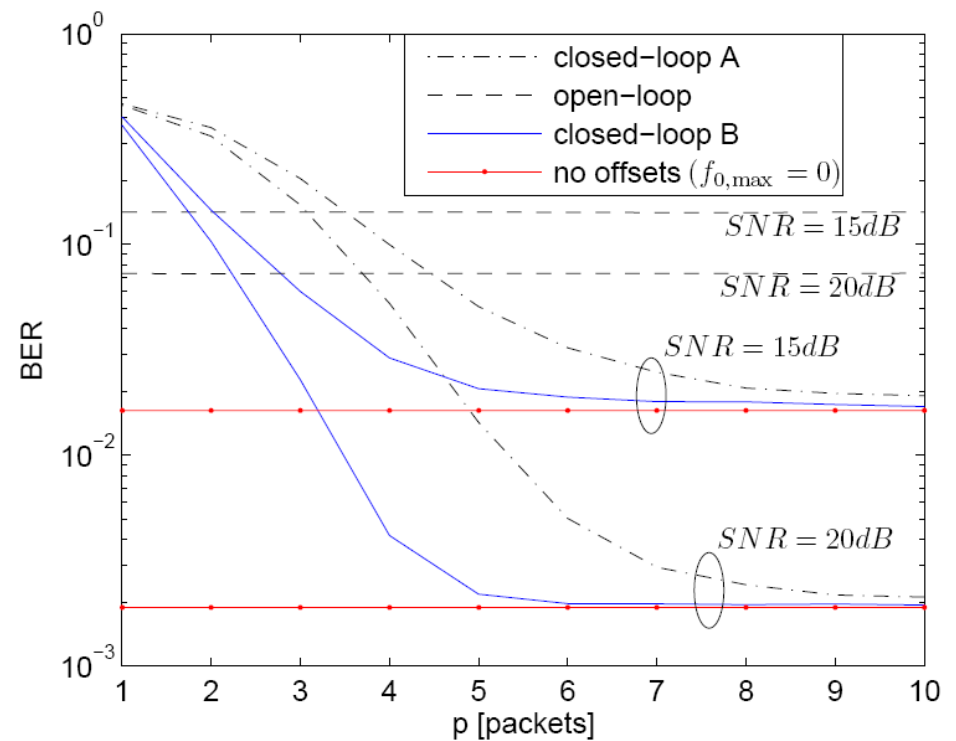
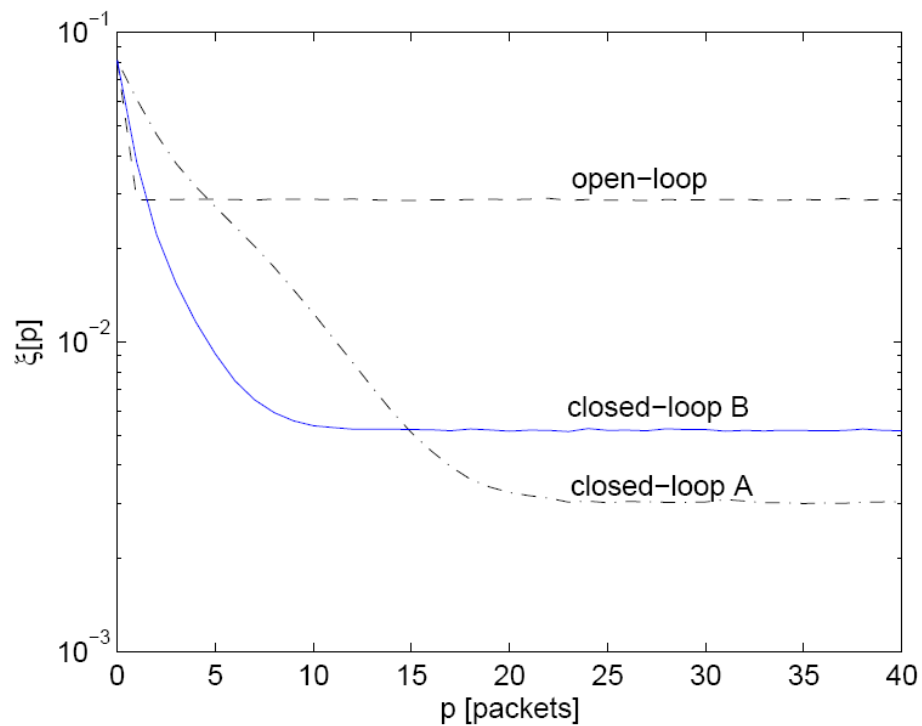
- when a node decodes the data payload of the transmitted packet(s), the local offset is computed based on the preamble signal(s)
- $f_k[n]$ is updated by combining the new offset with previous offsets according to the DFLL mechanism

❑ **Closed loop B:**

- all the nodes that are currently not transmitting (except the source) overhear the transmitted preamble(s) and update their carrier frequency according to DFLL

Simulation results

- Initial (norm.) carrier frequencies $\sim U(f_0-0.15, f_0+0.15)$
- 3 stages of relays
- 11 training symbols



Conclusions

- ❑ In packet-based wireless communication, DFLLs can attain frequency synchronization, without any master reference

- ❑ A novel frequency detector has been designed:
 - lower complexity as compared to FFT-based solutions;
 - suitable for implementation of DFLLs;

- ❑ Integration within a multi-hop multi-relay network employing DSTBC and packet based communication.