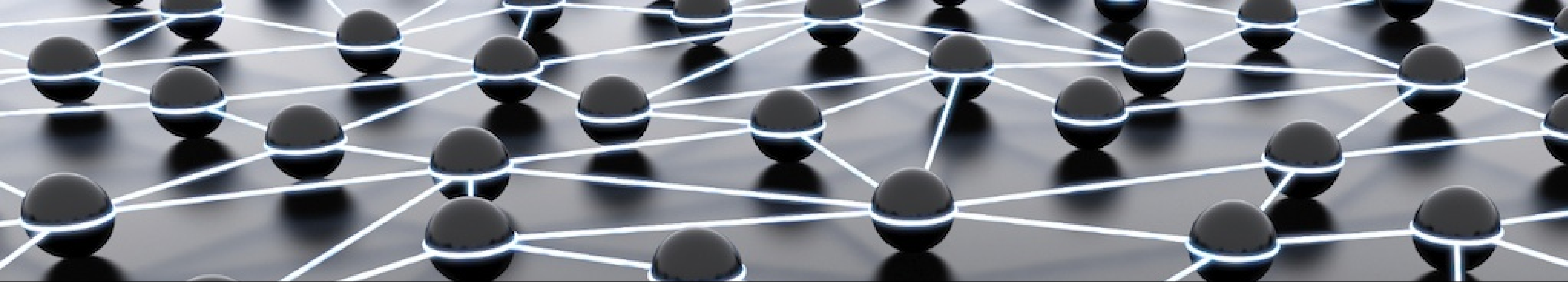
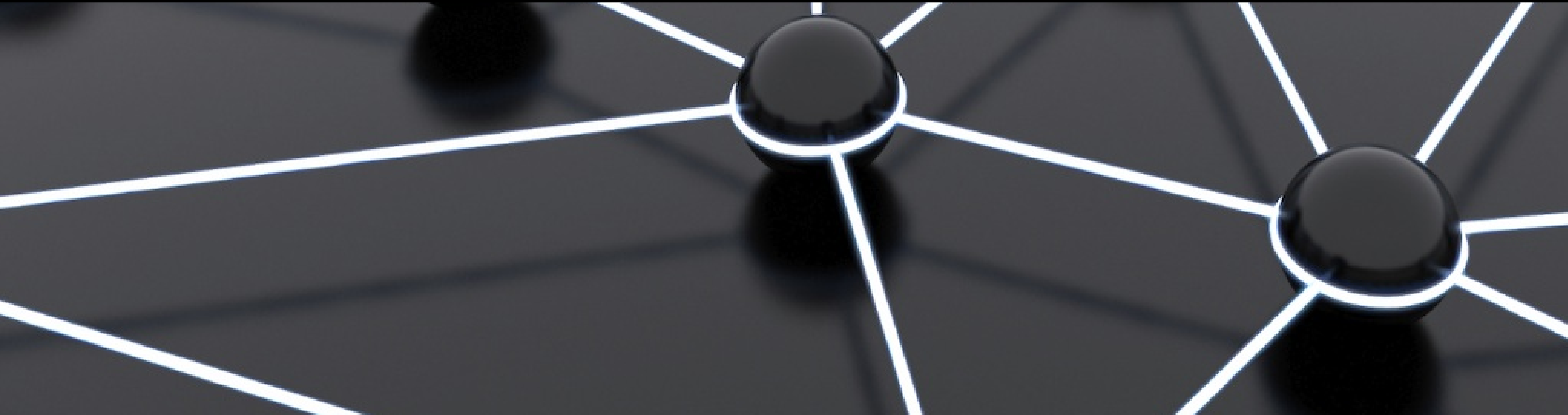


TSMP

Time Synchronized Mesh Protocol

Seminar in Distributed Computing, FS 2010, ETH Zürich

João Moreno



Overview

- Definition
- Background
- Protocol Details
- Results
- Conclusions

What is it?

The TSMP is a

- medium access and
- networking

protocol that provides

- reliable,
- low power and
- secure

communication in a managed wireless mesh network!

Also...

- scalable,
- flexible,
- low-maintenance,
- self-organizing,
- self-healing,
- wow!

Background Check

control

industrial

warning

monitoring

automation

alarm

Presented on **DSN 2008**, Orlando, Florida, USA

Kristofer S. J. Pister, Lance Doherty

Management

Yup, **managed** network.

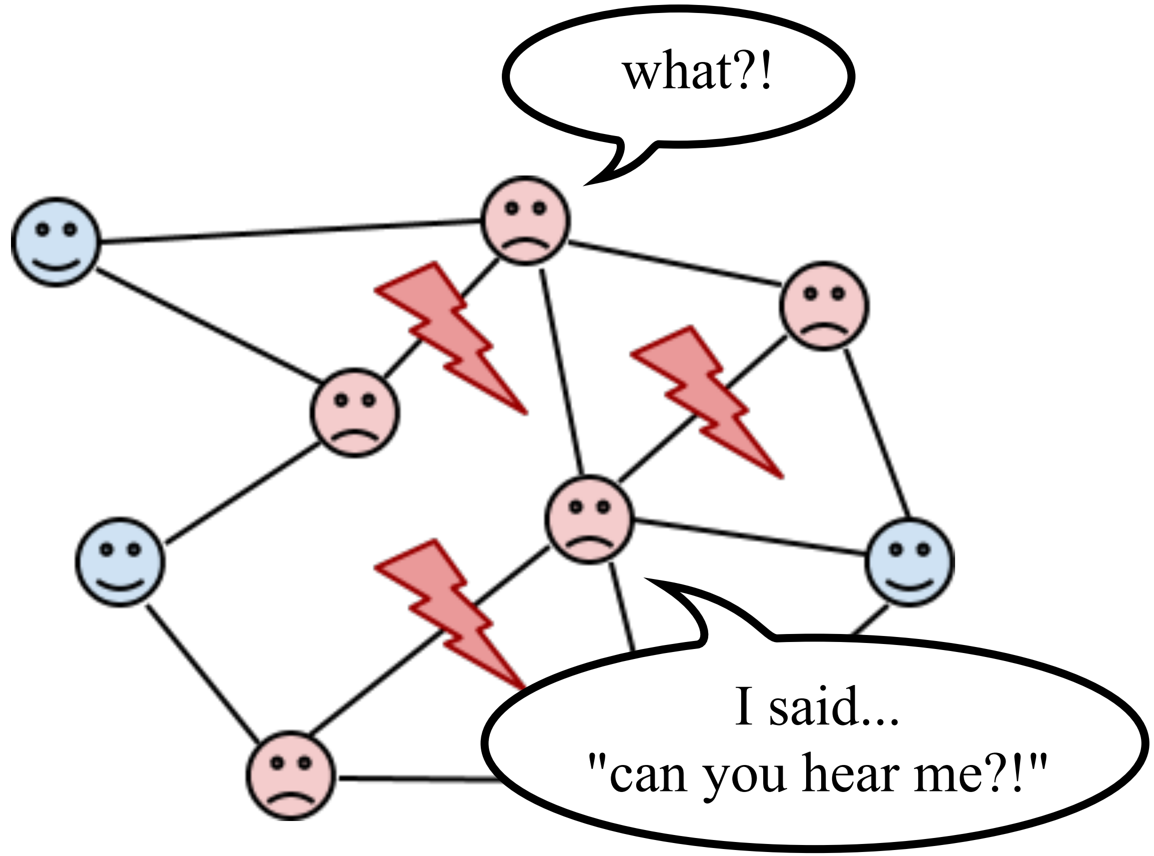
TSMP relies on the existence of a centralized controller to coordinate the communication schedule of the network. This guy is called the manager.

Real deployments show that scalability and robustness are no big issues.

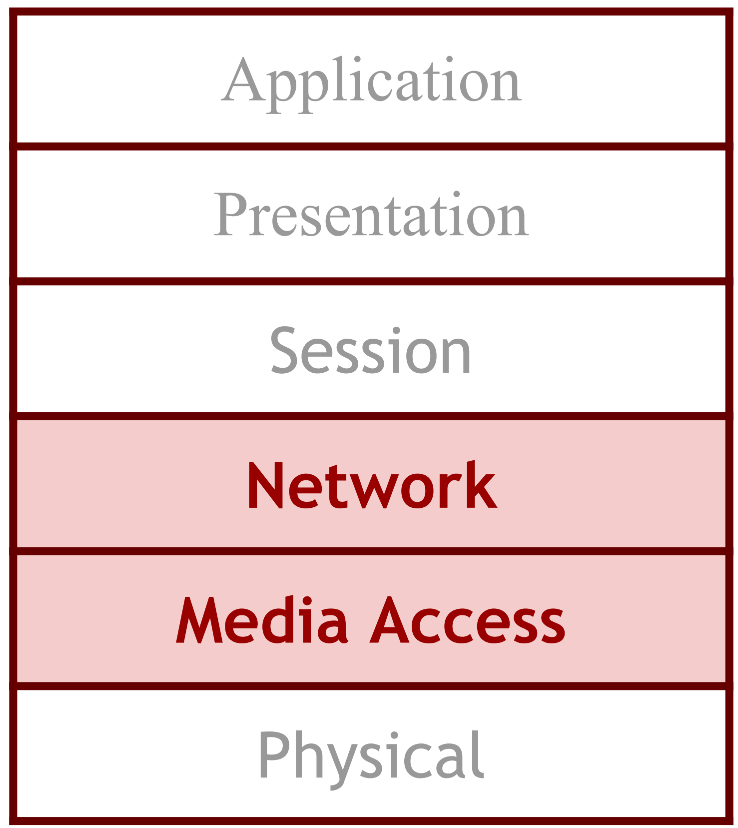
But the **limit** is somewhere.

Wireless Challenges

- Interference
- Blocked paths
- Node loss

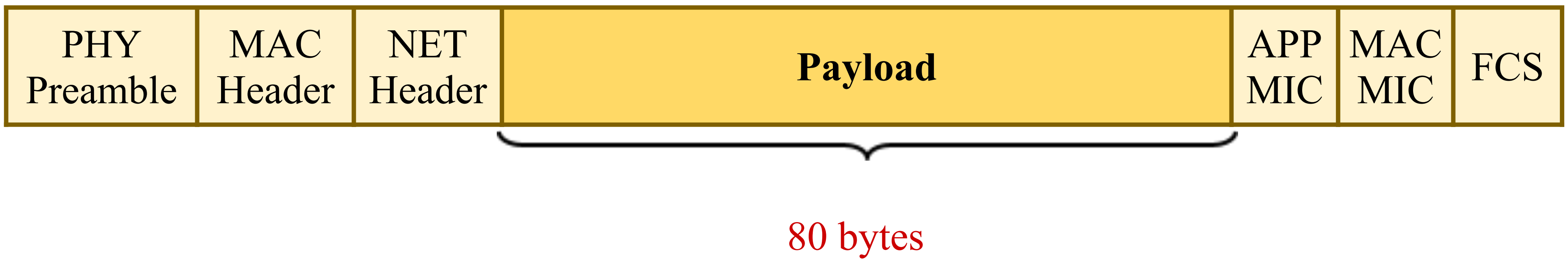


TSMP is all about...



MA
C

Packet format



In the **802.15.4** wireless standard,

- packet size is 127 bytes,
- of which 47 bytes are reserved by TSMP,
- leaving 80 bytes as payload.

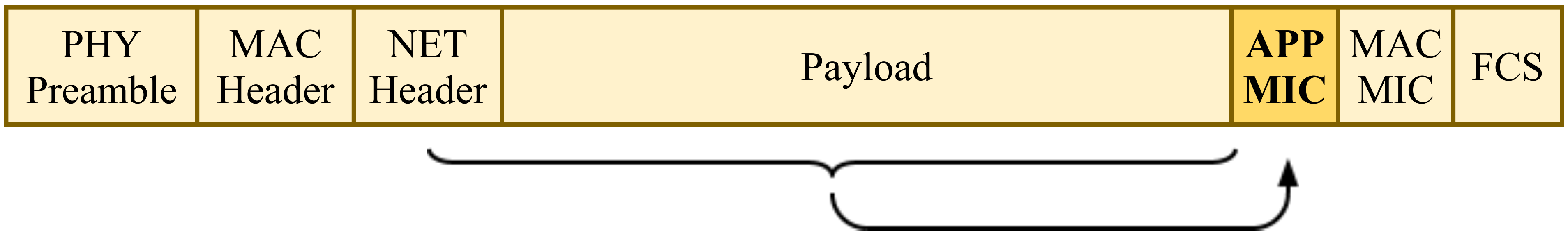
Packet format

PHY Preamble	**MAC Header**	**NET Header**	Payload	APP MIC	MAC MIC	FCS

The NET header contains information on End-to-End addressing and routing.

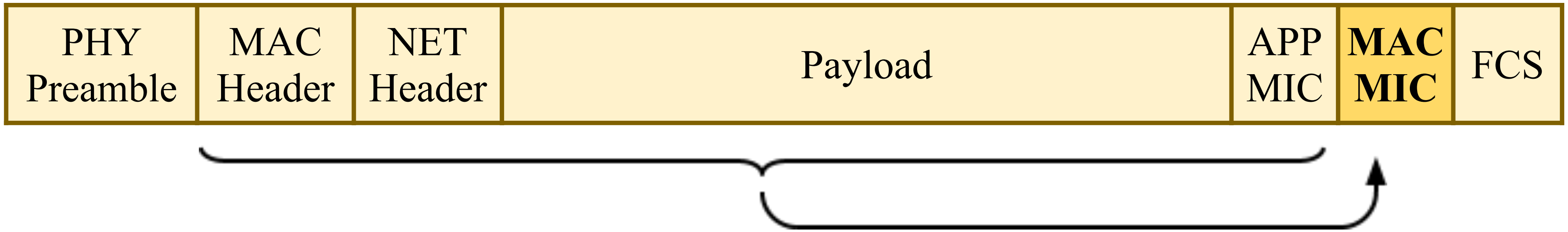
The MAC header contains information about Per-hop addressing and timing.

Packet format



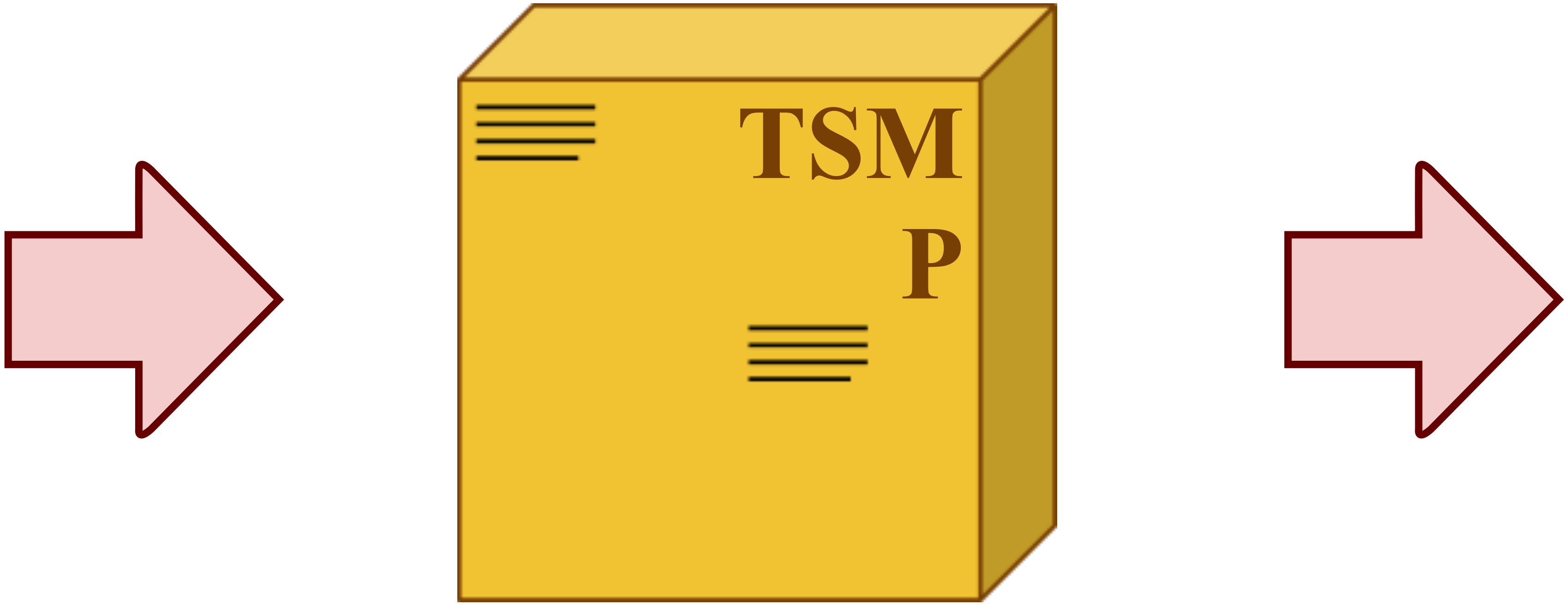
TSMP first constructs a Message Integrity Code of both the application layer payload and a nonce that resides in the Network Header.

Packet format



Then, the MAC Message Integrity Code is build from both headers, the payload and the previous MIC.

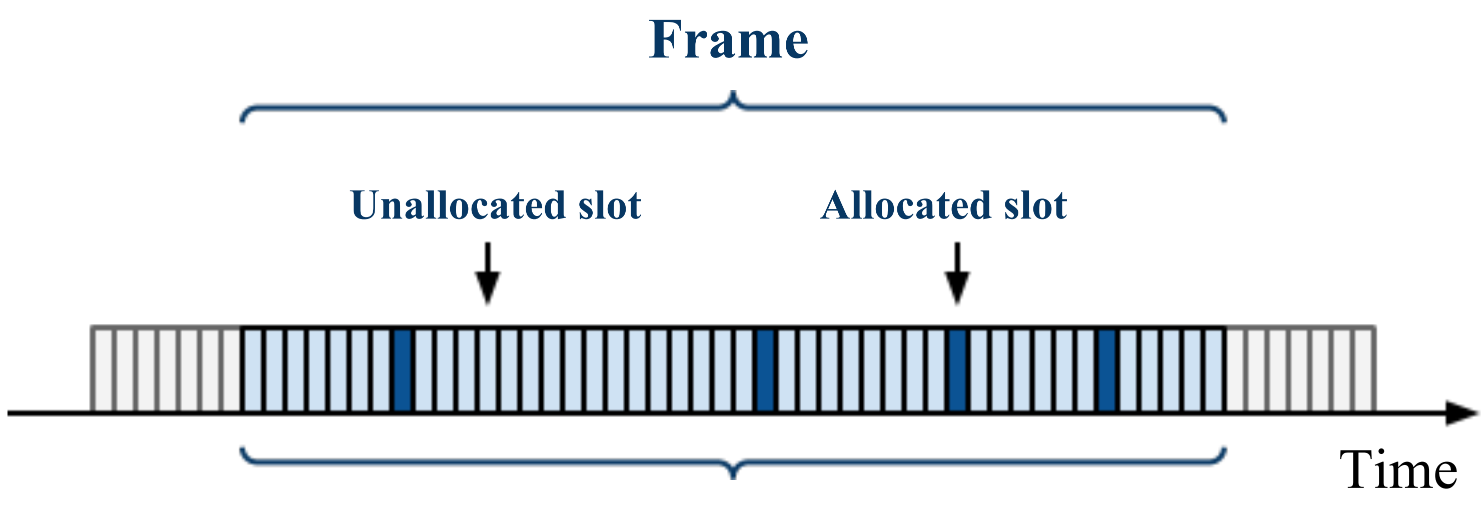
Nice packet!



1. TDMA

Time Division Multiple Access

Reduces interference from other TSMP nodes by scheduling communication in precise instances of time.



1. TDMA

Time Division Multiple Access

sync!

Synchronization

Rule #1: Do it well

Sync frequency

vs.

Energy consumption

Synchronization

Rule #2: Do it fast

Time spent sync'ing

vs.

Time gained by sync'ing

TSMP Synchronization

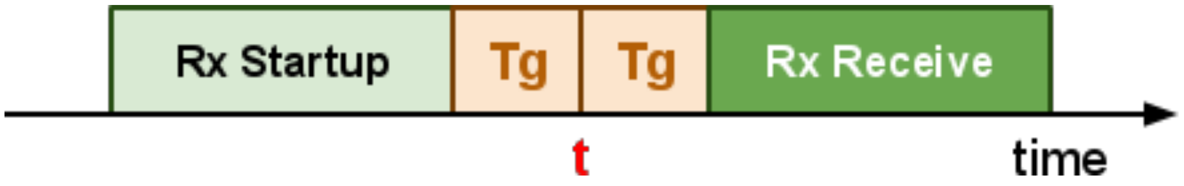
Time sync information is shared by piggybacking it with every ACK packet!

TSMP Synchronization

A node expects a packet at instant t.

Establish T_g seconds as the worst-case clock skew between any two nodes.

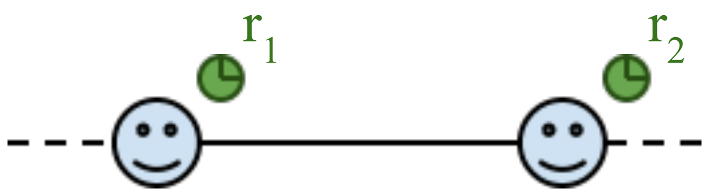
Guard time → $2T_g$



TSMP Synchronization

Given a guard time T_g, how often (T_{sync}) need two nodes to synchronize?

TSMP Synchronization



$\varepsilon \leftarrow r_2 - r_1$

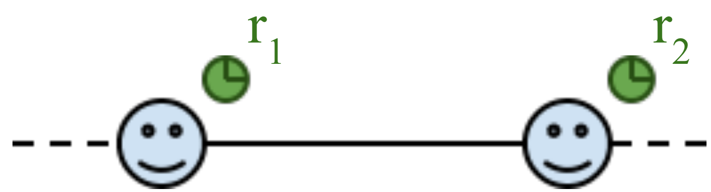
Once synced at t_0, synced again at t, with synch error δ.

Worst difference in shared time is $\Delta \mathbf{t}_{\mathbf{max}} = \varepsilon\,(t - t_0) + \delta$.

$$\Delta \mathbf{t}_{\mathbf{max}} < \mathbf{T}_{\mathbf{g}}$$

$$(t - t_0)_{max} = \mathbf{T}_{\mathbf{sync}} < (\ \mathbf{T}_{\mathbf{g}} - \delta\ )\ /\ \varepsilon\ !!!$$

TSMP Synchronization



$$T_{sync} < (T_g - \delta) / \varepsilon$$

For example, define a guard time of **±1ms**, **50μs** of synch error and **±10ppm** of rate difference between two nodes...

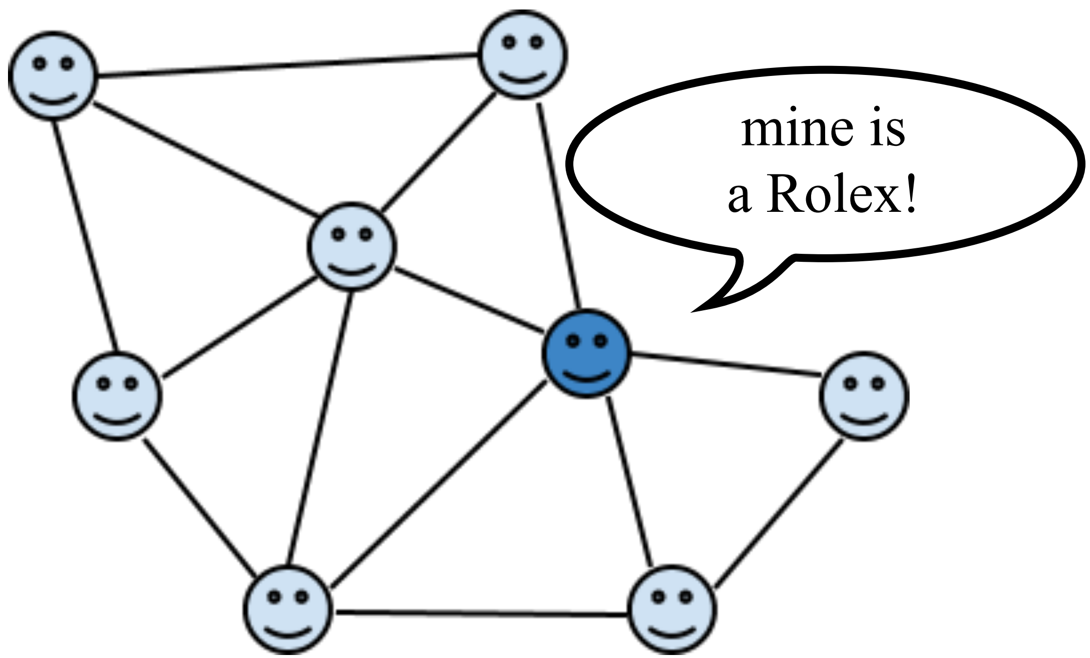
... they need to be synchronized every **48s**!

TSMP Synchronization

What if they're not?

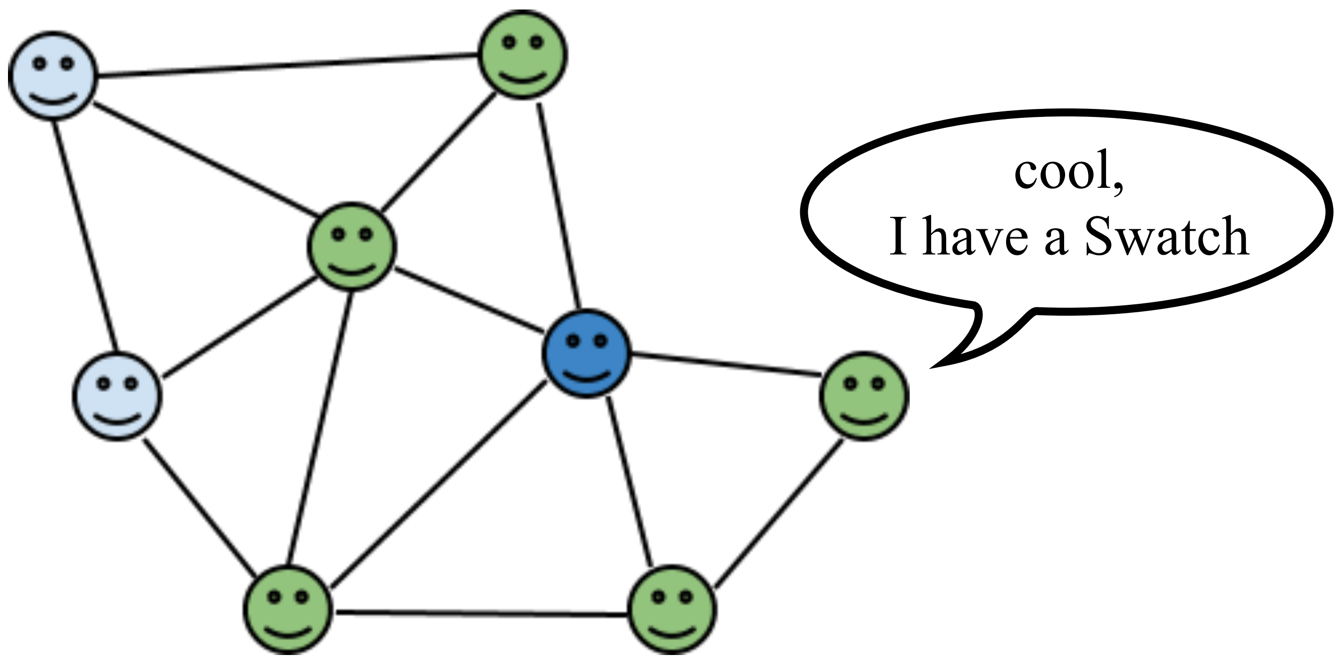
brb...

TSMP Synchronization



Time is propagated from a single time-master...

TSMP Synchronization



... through a loop-free graph of participating nodes, creating a parent-child like hierarchy.

TSMP Synchronization

What if they're not?

Parents can broadcast beacon packets.

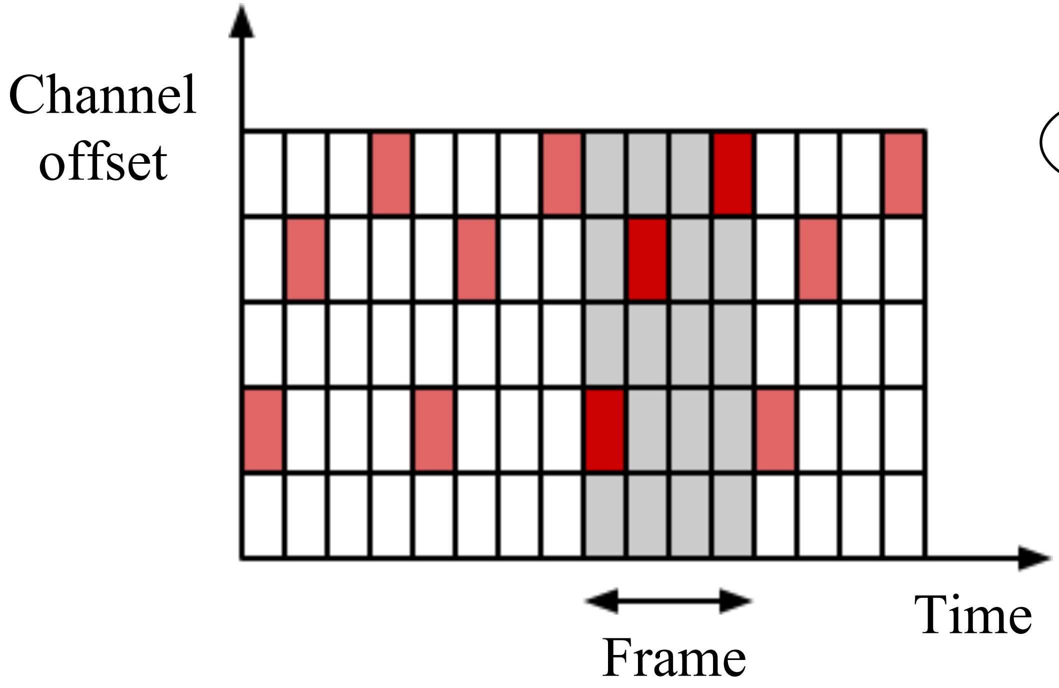
Children can send keepalive packets.

Ultimately how often your nodes will sync depends on the type of network installed: periodic data-gathering, alert-based, et al.

2. FHSS

Frequency-hopping Spread Spectrum

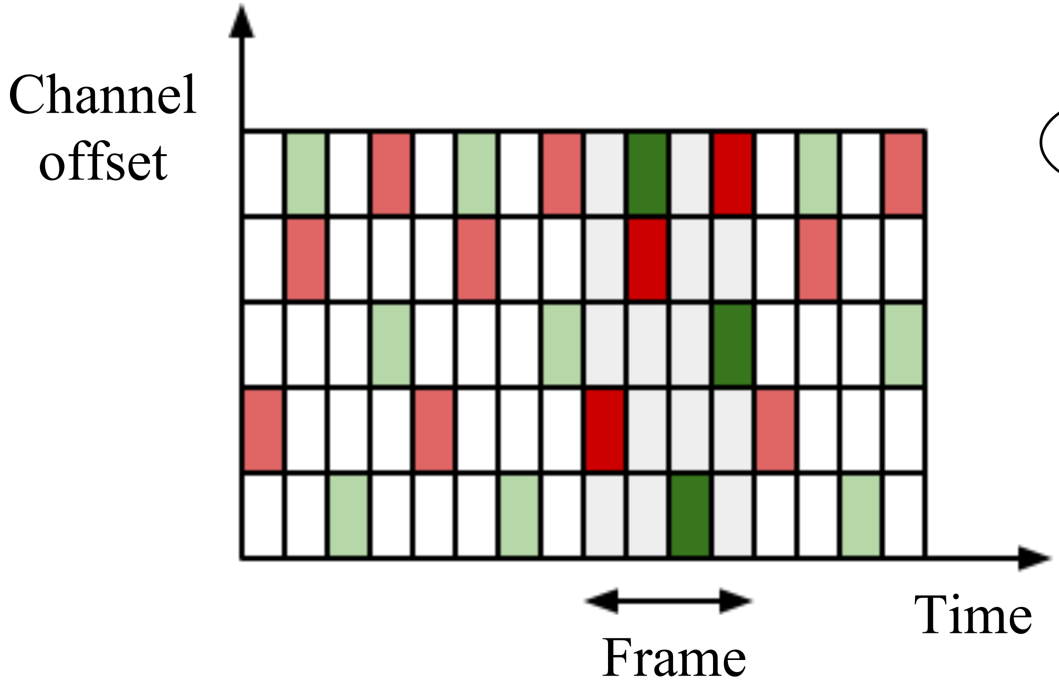
Reduces interference probability by spreading the signal over several channels, using different frequencies.

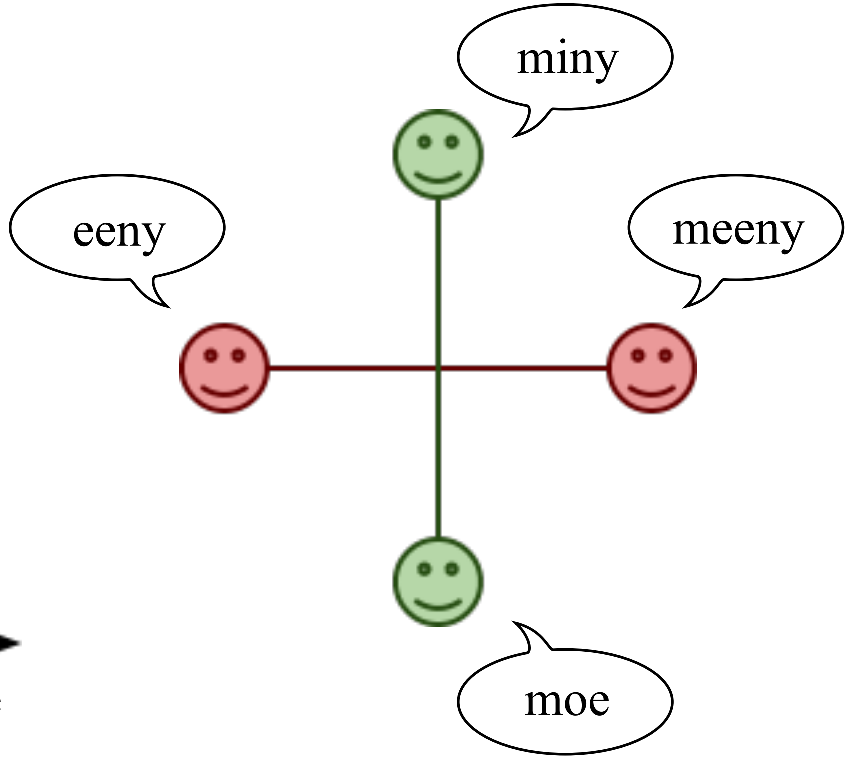


2. FHSS

Frequency-hopping Spread Spectrum

Also, it increases bandwidth in the order of the number of channels!





TSMP Channel Hopping

Channel = Lookup[(ASN + Offset) % ***#Channels***]

Lookup is a randomly sorted loop-up-table with values ranging from 0 to ***#Channels***-1.

ASN stands for the Absolute Slot Number since the beginning of the network.

Communication happens in **links** which are characterized by their offsets (more on links later).

Bandwidth

Using the **802.15.4** wireless, with 16 channels,
60 time slots per second and 80 bytes of payload,

theoretically we get

16 * 60 * 80 = 76.8 KB/second

of **application level bandwidth.**

Network Maintenance

But, do remember that TSMP reserves time slots for

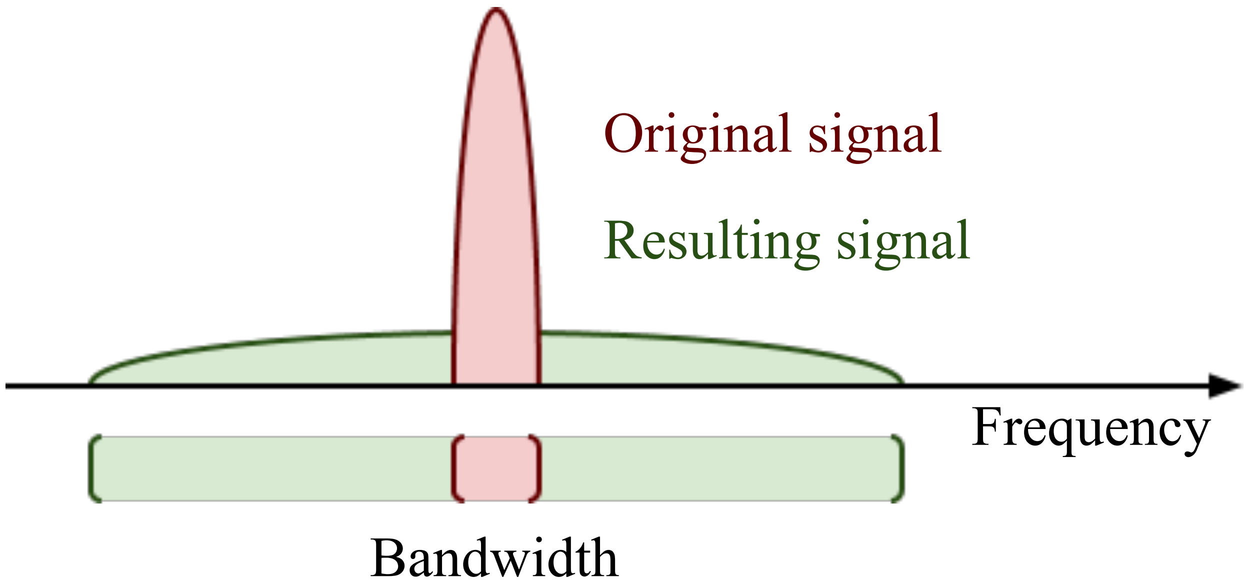
- network configuration,
- neighbor discovery and
- join requests listening.

This will come in handy in a sec...

3. DSSS

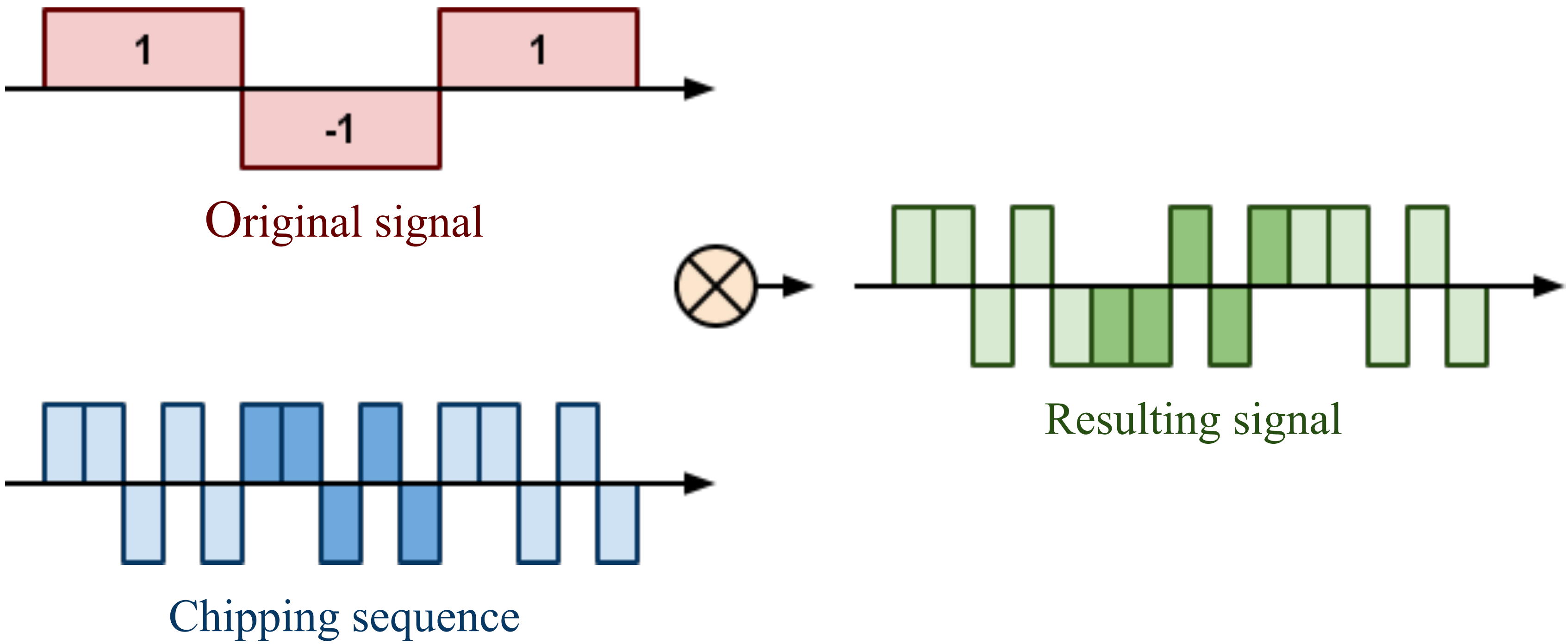
Direct-sequence Spread Spectrum

Reduces interference probability by spreading the signal over more bandwidth.



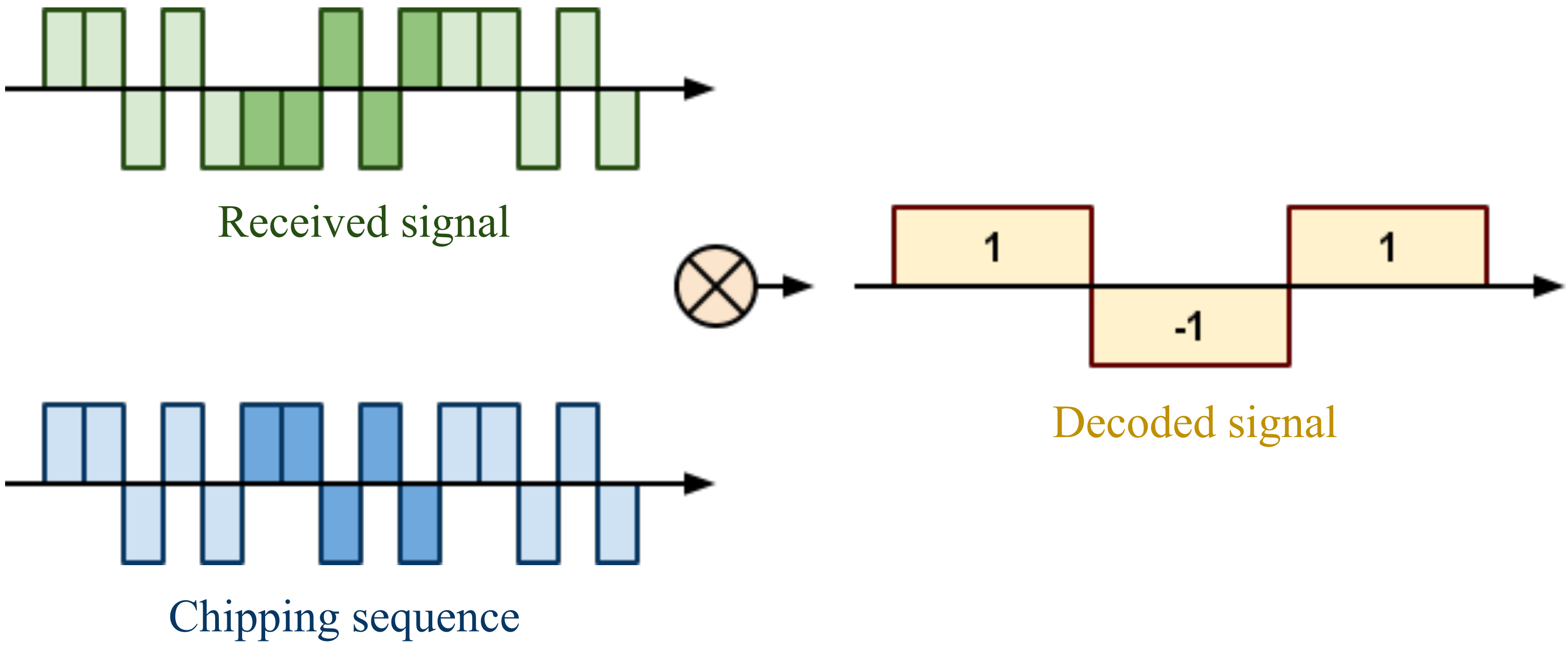
3. DSSS

Direct-sequence Spread Spectrum



3. DSSS

Direct-sequence Spread Spectrum



Extra: Link-Layer ACKs

One more thing...

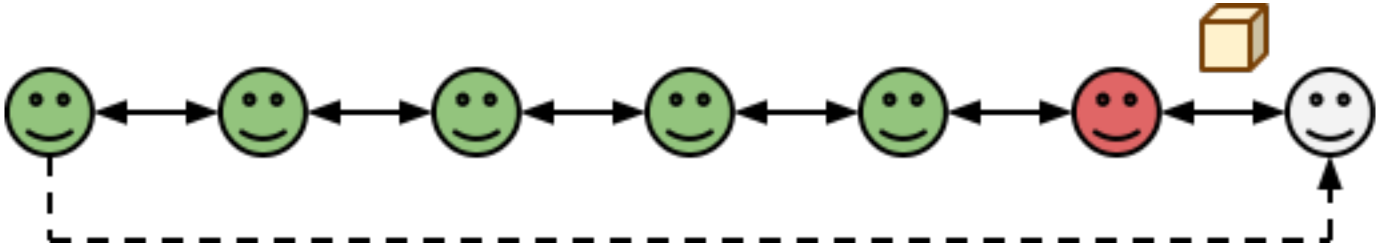
ACKs are generated on the Link layer!

PHY Preamble	MAC Header	NET Header	**Payload**	APP MIC	MAC MIC	FCS

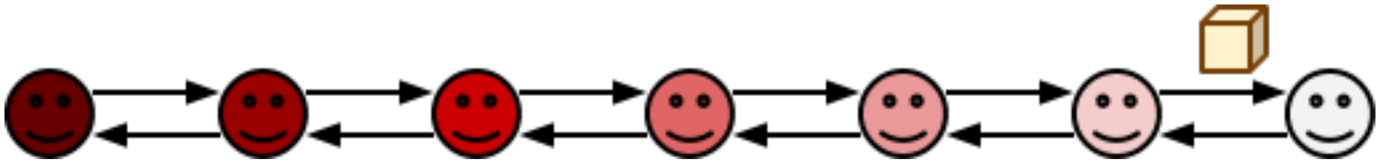
After FCS and MAC MIC verification,
a positive or negative ACK is sent back accordingly.

Extra: Link-Layer ACKs

Provides reliability without too much overhead by doing this:



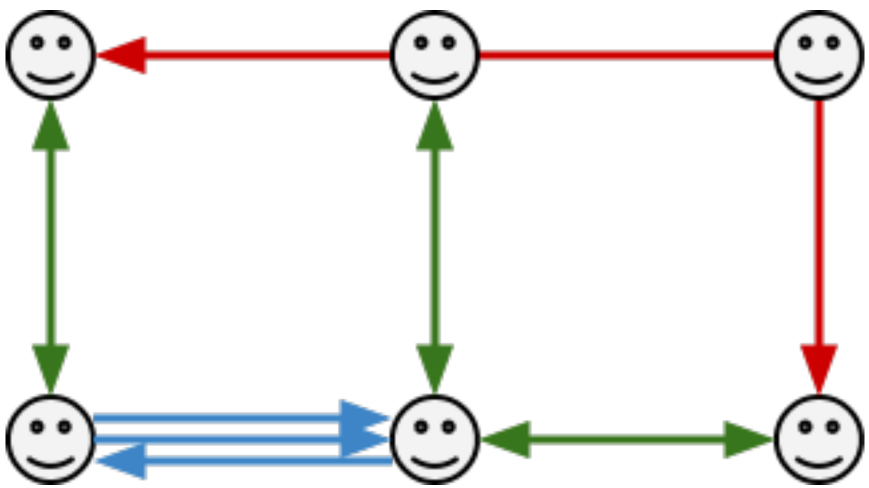
instead of this:



NET

Definitions

Paths, routes, links, oh my!

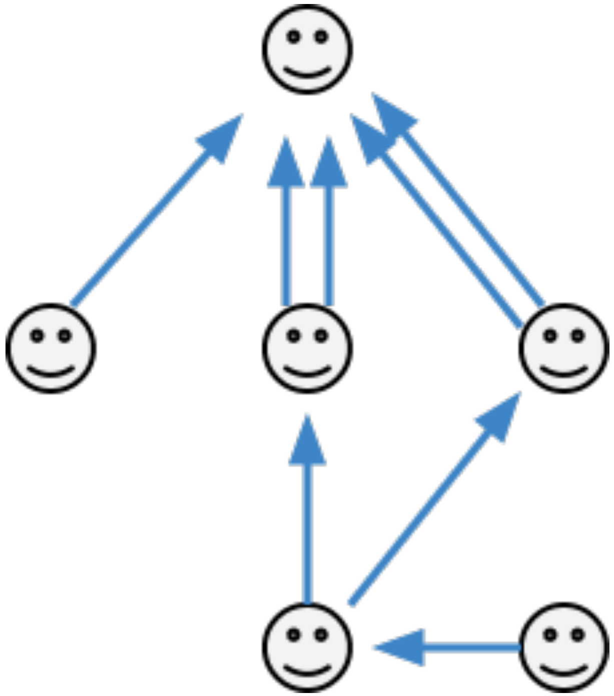


Links are requested to the manager and with more links comes more bandwidth!

Graph Routing

Link allocation creates graphs of data flow!

Multiple communication graphs in the same network are possible.



Definitions

A network is a set of nodes that share a network ID, typically rooted by a gateway node that is both

- the timing master and
- responsible for relaying network configuration.

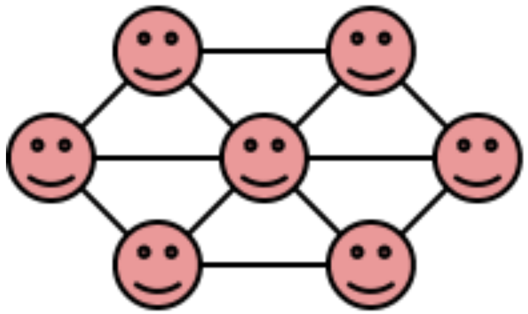
But: ***"all nodes are created equal"***.

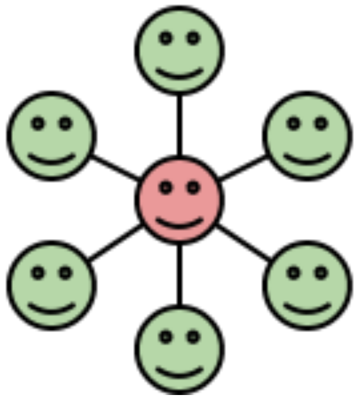
Mesh Routing

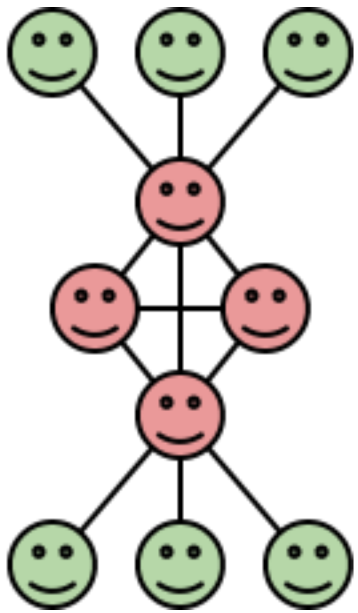
A router node might become an end node, throughout the existence of the network, and vice-versa.

Flexibility, extendability, scalability.

Configurability too!



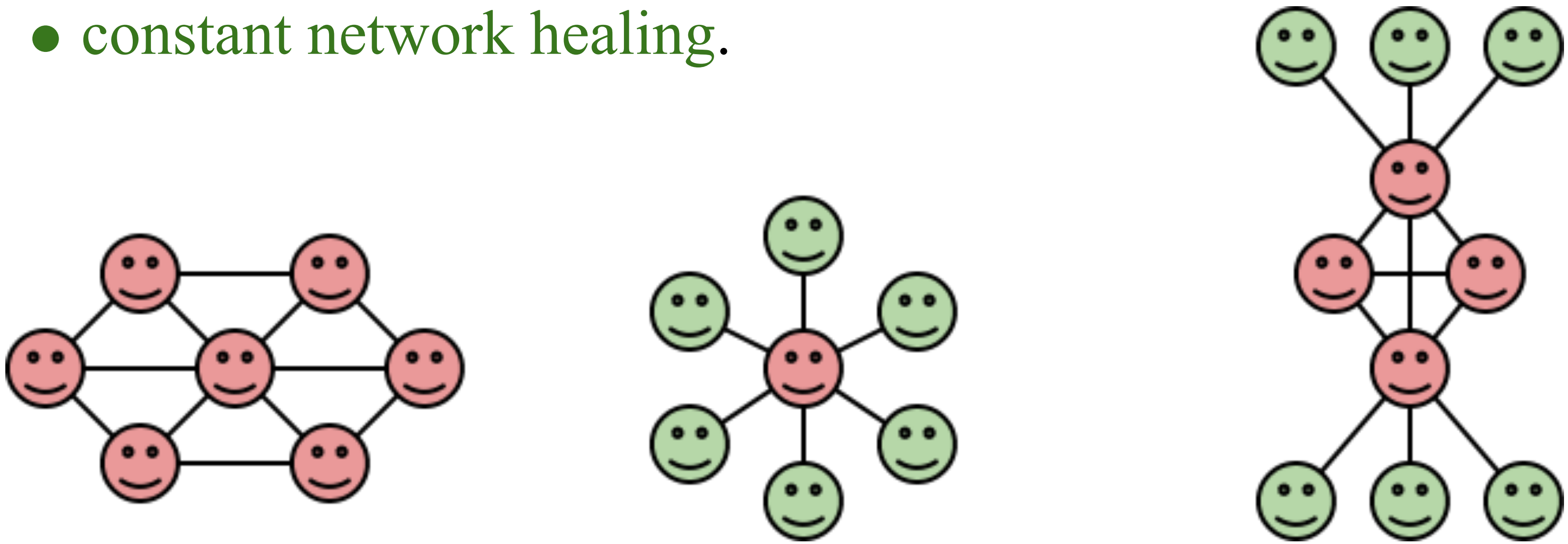




Mesh Routing

TSMP provides fully redundant mesh routing and relies on both

- automatic node joining and
- constant network healing.



Fully Redundant Routing

"Redundancy by diversity"

Spacial diversity by maintaining multiple parent nodes and requesting links that connect to them.

Temporal diversity by retry (ACKs) and failover mechanisms (memorization of missing ACKs).

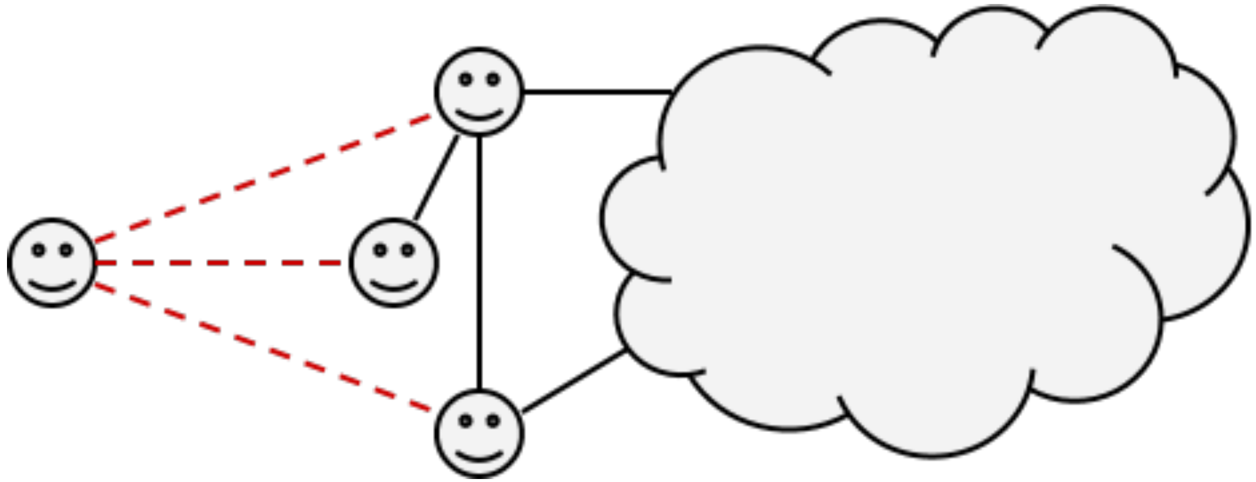
Joining a Network

A node tries to join a network by scanning several frequencies, looking for some communication going on.

Joining a Network

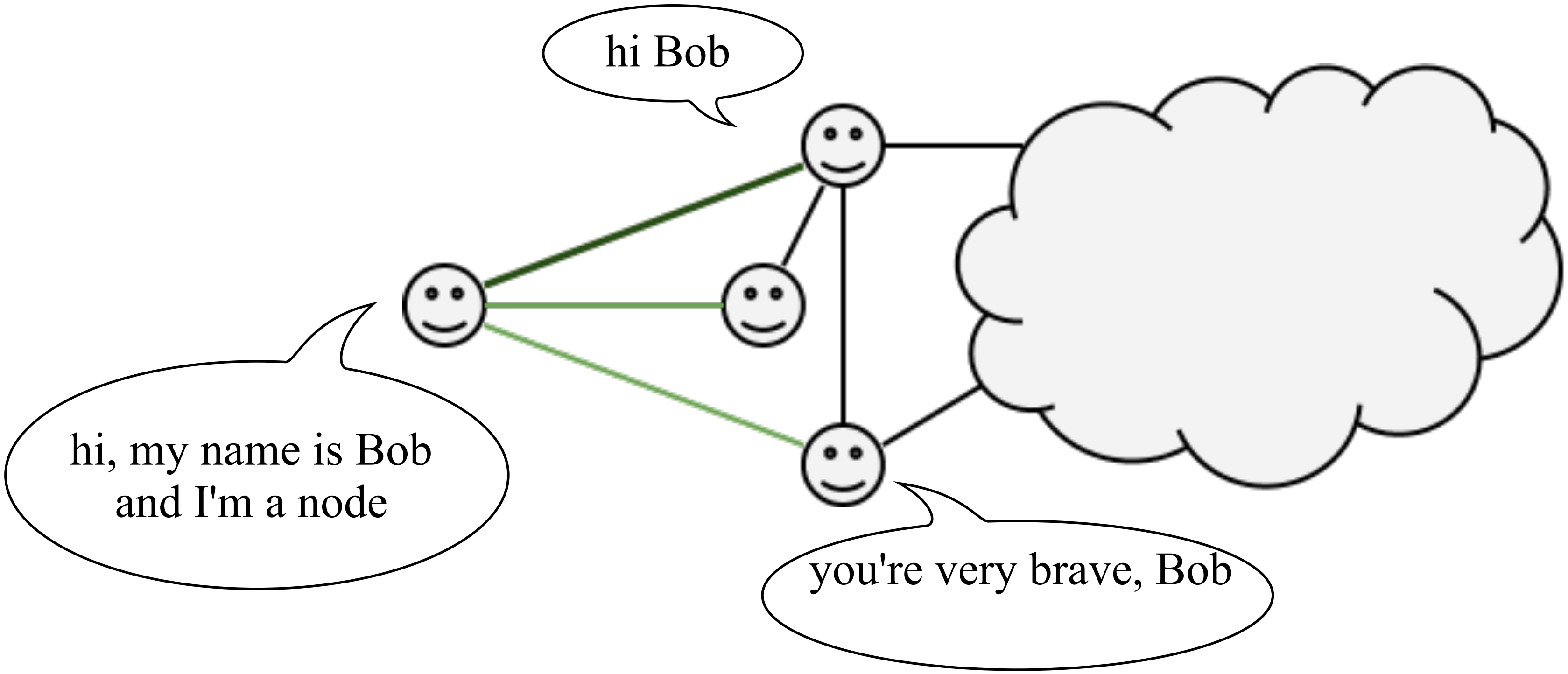
Once it listens to a network advertisement, it can synchronize with the network. Then, it continues the search for neighbors, but only using the time slots.

Joining a Network



It builds a neighbor list and sends it in a join request to the network. Eventually, the manager will receive, evaluate and respond to it.

Joining a Network



The manager assigns it some links, and after choosing its parent (s), it gets warmly welcomed in the group.

Healing

Periodic health reports are sent to the manager and have statistics like

- MAC packets transmitted and failed,
- APP layer packets dropped,
- battery life, etc.

They provide the manager the right information for graph modifications and efficient link management.

Network Modification

Periodic neighbor discovery allows TSMP to stay in constant evolution by taking advantage of the temporal changes that might happen in the network.

This provides network optimization as well as repair.

Might be turned off for energy saving purposes.

Security

The NET layer

- encrypts the application payload and
- authenticates the payload and NET header.

The MAC layer

- authenticates the entire packet.

Integrity is guaranteed via both the NET and MAC MICs.

Security

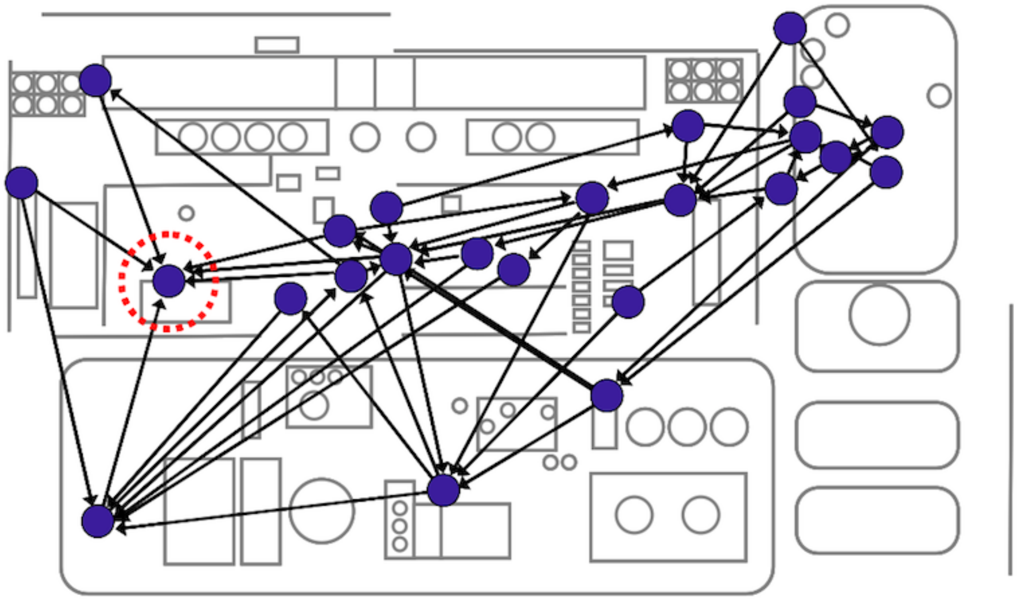
Encryption is a centralized security mechanism.

Every network has a pre-configured Join Key.

Upon joining a network with the right Join Key, and having been identified, a node is sent

- a Session Key, pseudo-randomly generated by the manager, used for encryption, and
- the Network Key, used for authentication.

Results - Range



Network range over 400m

Coker unit at oil refinery

- 24 nodes,
- no initial config,
- several hops of over 100m,
- installation performed by contractor.

Reliability > 99.97% !

Results - Reliability

Print shop

- 44 nodes,
- 3-floor, 15.000m^2 concrete and steel structure,
- environment heavily equipped with machines.

Measurements over 26 days recorded
17 out of **3.6 million packets** lost!

Even with occasional paths' stabilities
going down to **null** for entire days.

Conclusions

Time sync enables better performance in low-power networks than in an async fashion.

Channel hopping provides higher stability and bandwidth.

Link allocation for graph routing is the secret towards flexibility.

Central management can indeed provide commercially interesting deployments (up to hundreds of nodes).

Thanks!