HALMSTAD UNIVERSITY

Time Synchronization and Frequency Hopping

Urban Bilstrup

101013

Outline

- Time Synchronization
  - Introduction
  - Time server
- Frequency Hopping Spread Spectrum
  - Introduction
  - Hopping pattern

2

Time Synchronization

Time Synchronization - Why?

- Many complex control systems are implemented as a distributed computer system.
- When such system is used to control some physical process, which obeys strict physical laws, timing problems can arise.
- In theory time-invariance is usually assumed, and it is common to assume **equidistant sampling** in a computer controlled system.

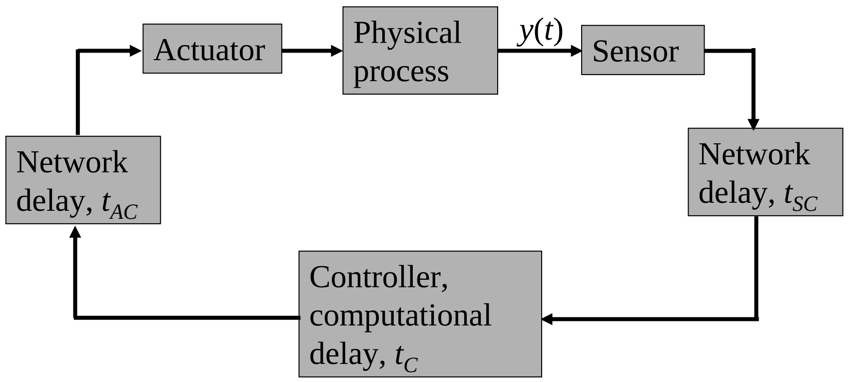
Time Synchronization - Why?

- But, time-invariance is not apparent when control loops are closed over a communication network.
  - It is difficult to guarantee a constant control delay over a network.
  - To do so global scheduling and synchronization are required.

Time Synchronization - Delay

- Communication delay between the sensor and the controller, T_{SC}
- Computational delay in the controller, T_C
- Communication delay between the controller and the actuator, T_{CA}

Time Synchronization - Delay



7

Time Synchronization - Delay

- If these delays are constant it is easy to take the delay into consideration in the design of the controller.
- It is more difficult to design controllers for time varying systems.
- Considering a system with a $T_{TOT}(t)$, supose that $T_{TOT}(t)$ is time varying in an unknown fashion but is bounded by $T_{TOT}(t) < T_{max}$.
- Designing the control system for a worst case scenario, e.g. $T_{TOT}(t) = T_{max}$ do not guarantee that the system is stable.

8

Time Synchronization – Proposed solution

- To mitigate the negative effects of a time varying system, timeliness becomes the most critical aspect.
- When actuation is necessary use an as “fresh” sample as possible.
  - Synchronization towards the sampling instants
  - Synchronization towards the actuation instants
- We must assume that the total delay is less then one sample period.
- Time synchronization between the devices is necessary to achieve this.

9

Time Synchronization – Time server

- A **time server** is a server computer that reads the actual time from a reference clock and distributes this information to its clients using a computer network.
- The time server may be a local network time server or an internet time server.
- The most important and widely-used protocol for distributing and synchronizing time is the Network Time Protocol (NTP), though other less-popular or outdated time protocols continue in use.

10

Time Synchronization – Time server

- The time reference used by a time server could be another time server on the network or the Internet, a connected radio clock or an atomic clock.
- The most common true time source is a GPS or a GPS master clock.
- Time servers are sometimes multi-purpose network servers, dedicated network servers, or dedicated devices (all a dedicated time server does is provide accurate time).

11

Time Synchronization – Time server

- An existing network server (e.g. a file server) can become a time server with additional software.
- The NTP homepage provides a free and widely-used reference implementation of the NTP server and client for many popular operating systems.

12

Simple Network Time Protocol

- RFC2030 - Simple Network Time Protocol (SNTP) Version 4 for IP .
  - NTP timestamps are represented as a 64-bit unsigned fixed-point number, in seconds relative to 0h on 1 January 1900.
  - The integer part is in the first 32 bits and the fraction part in the last 32 bits.
  - In the fraction part, the non-significant low order can be set to 0.

```
                     1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Seconds                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Seconds Fraction (0-padded)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

13

Simple Network Time Protocol

```
                     1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|LI | VN  |Mode |    Stratum    |     Poll      |   Precision   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Root Delay                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Root Dispersion                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Reference Identifier                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                   Reference Timestamp (64)                    |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                   Originate Timestamp (64)                    |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                    Receive Timestamp (64)                     |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                    Transmit Timestamp (64)                    |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Key Identifier (optional) (32)                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                                                               |
|                 Message Digest (optional) (128)               |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

14

Simple Network Time Protocol

- To calculate the **roundtrip delay**, *d,* and **local clock offset**, *t*, relative to the server, the client sets the transmit timestamp in the request to the time of day according to the client clock in NTP timestamp format. The server copies this field to the originate timestamp in format.
- The server copies this field to the originate timestamp in the reply and sets the receive timestamp and transmit timestamp to the time of day according to the server clock in NTP timestamp format.
- When the server reply is received, the client determines a Destination Timestamp variable as the time of arrival according to its clock in NTP timestamp format.

Simple Network Time Protocol

- Originate Timestamp T1 time request sent by client
- Receive Timestamp T2 time request received by server
- Transmit Timestamp T3 time reply sent by server
- Destination Timestamp T4 time reply received by client

The roundtrip delay *d* and local clock offset *t* are defined as:

- d = (T4 - T1) - (T2 - T3)
- t = ((T2 - T1) + (T3 - T4)) / 2.

Frequency Hopping Spread Spectrum

17

Spread Spectrum

- Spread spectrum refers to wireless system producing a frequency spectrum much wider than the bandwidth of the information signal

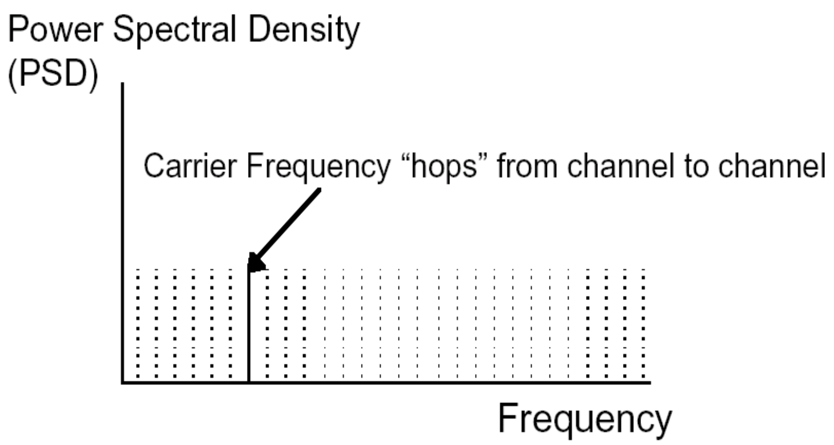
- Research efforts during World War II
  - Secure communications in military environments
  - Classified until the 1970s

18

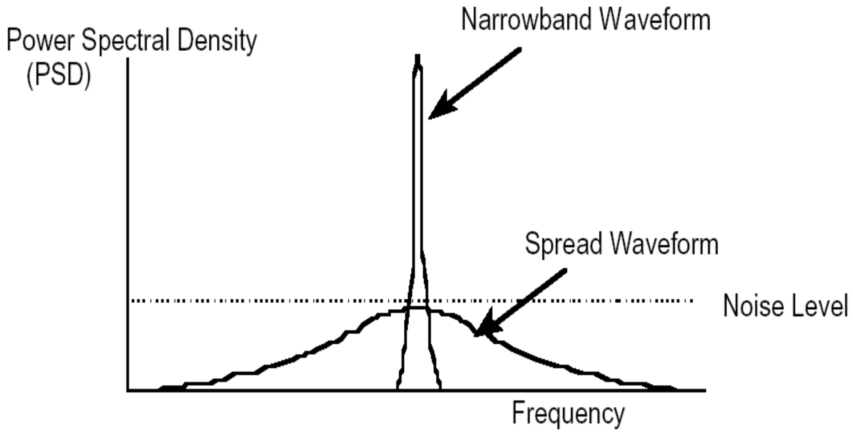
Spread Spectrum

- There are different types of spread spectrum, most common are:
  - Direct Sequence Spread Spectrum (DSSS)
  - Frequency Hopping Spread Spectrum (FHSS)
  - Time Hopping Spread Spectrum (THSS)

FHSS

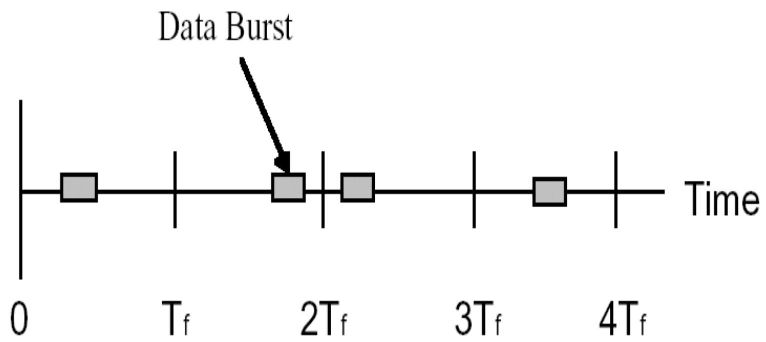


DSSS



21

THSS



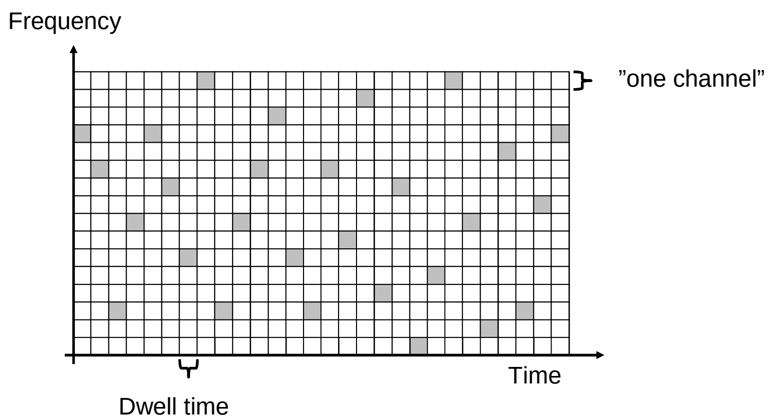
22

FHSS

- FHSS spreads its signal in a wide frequency band by using frequency hopping.
- We send our data as usual but we change our frequency during the transmission.
- The sender and receiver must both know the hopping sequence.
- Comes in two flavours:
  - Fast hopping
  - Slow hopping

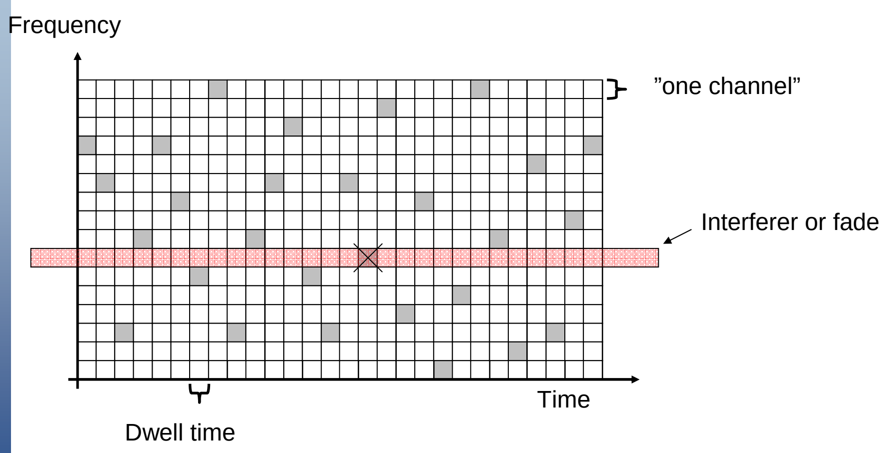
23

FHSS

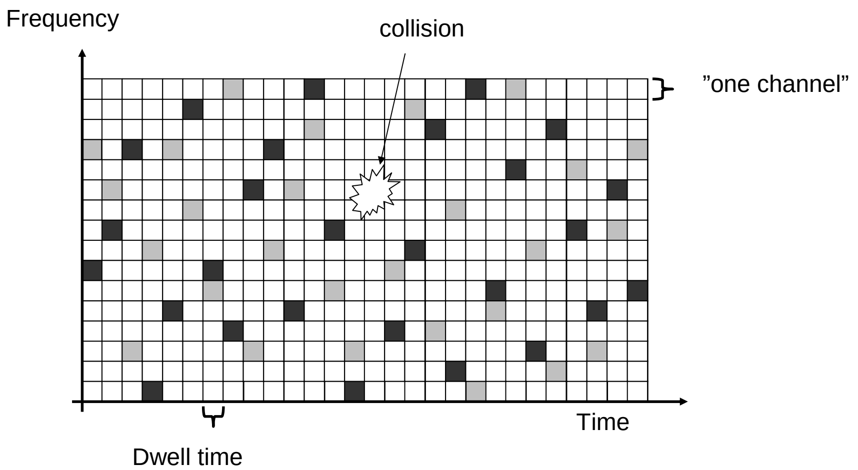


24

FHSS – Interferer/fade



FHSS – two senders non-orthogonal sequences



FHSS – orthogonal sequences

- For example if the basic hopping sequence is HS1={1, 2, 3, 4, 5 …. 78, 79}, the second is HS2={79, 1, 2, 3, 4, 5 …. 77, 78}, and so forth until HS79= {2, 3, 4, 5, 6 …. 79, 1}.
- If all those 79 sequences are shifted synchronously every second time slot, 79 orthogonal channels are available.
- All nodes must be time-slot synchronized in their transmissions !