Exercise Sensor Networks - (till June 20, 2005)

Lecture 8: Synchronization in sensor networks

Exercise 8.1: Signal propagation delay

A church bell is rang by a digitally triggered mechanics. How long does the sound travel to a sensor node in a distance of 2km if sound travels at 300m/s?

In another setting a node hears the radio synchronization signal of the "Physikalisch-Technischen Bundesanstalt" (federal ministry for physics and technology) in a distance of 1.800km. Radio signals propagate at a speed of 300.000 km/s. How large is the delay?

Solution:

2000m / 300ms = 6,667 s

The delay will be about 6,667 seconds.

1800/300.000 = 6 ms

Even when using radio signals the delay is still 6 ms. So one can not conclude that radio propagation delays do not play any role. In space missions, the delay can accumulate to an amount that does e.g., not allow to navigate vehicles on the mars interactively anymore.

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Exercise 8.2: Reference Broadcast Synchronization

Node A receives the last acoustic synchronization signal 2000ms (milliseconds) after its initialization. At time 2100ms it detects an event.

At 3400ms B tells A that B has detected the same event 1700ms after its initialization. B's last synchronization took place at 1500ms. Sound travels at a speed of 300 meter/second and all acoustic synchronization signals origin from the same global source.

a) How many ms did B detect the event sooner or later than A, based on the given information. For what reasons may your result contain some uncertainty?

Solution:

At the synchronization event B's clock showed 1500ms, the one of A 2000ms. So the time of B corresponds to the time of A minus 500ms. If B detected the event at 1700ms this corresponds to 1700+500=2200 in the time domain of A. So B perceived the event 100ms later than A.

However, we deal with two different phenomena, namely the signal propagation delay of the event and the delay of the synchronization signal. So the difference in the perception of the event of 100ms is correct only if both nodes were synchronized at the same time resp., if they have the same distance from the synchronization source.

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Exercise 8.2: Reference Broadcast Synchronization

b) In addition it is now known that node A is 100 meters away from the sync. source and node B 300 meters. How can the precision of the result from a) be improved?

Solution:

Now we know that the sync. signal has to travel an additional 200 meters to reach B (with respect to A).

This takes the sound 200/300 = ca. 667ms. This time must be subtracted from 100ms which means that in fact B hears heard the event 567ms earlier than A.

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Exercise 8.3: Estimation of a time interval with uncertainty

3400ms after its initialization node B receives a message from node A that an event has happened. Node A tells in addition that its clock showed 7800ms when A got to know about the even itself. Then some time passed and A informed B about the even at time 8400 (according to A's clock).

According to B's clock it sent the last message to A at time 1200ms. Node A also tells B in the message that it did not hear from B for a time span of 2000ms.

Finally it is known that B's clock has a maximum deviation of p_B=0.08 (this means that the clock is at most too fast about the factor 1+0.08 and at most too slow about the factor 1-0.08). A's clock has a max. deviation of p_A=0.1.

a) Obtain an interval as small as possible but which is large enough so that it must contain the event.

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Exercise 8.3: Estimation of a time interval with uncertainty

Solution:

B is told about the event at (its) time 3400. Without any further information 3400 can be used as upper and lower bound for the event. We will then have to decrease the lower bound as much as possible and the upper bound as little as possible.	[3400, 3400]
Node A lets 8400-7800ms pass according to its clock before telling B about the event. For calculating the lower bound that B's clock is too fast and A's clock is too slow. In other words: A time unit of node A takes much longer from B's perspective. When calculating the upper bound we assume the opposite. But we must not fully ignore the waiting time of A for the upper bound (because it actually did take place).	[3400-(600x1.08/0.92), 3400-(600x0.92/1.08)] = [2696, 2888]
Finally the packet delay has to be considered. Ideally the one-way delay would be a good choice. But since we do not know how the round tip time is divided into the way forward and back we assume as a secure estimate as a lower bound that the packet traveled from A to B in no time and as an upper bound that it took the full round trip time. The two way packet delay is composed of the time between B communicating with A for the last time and the arrival of A's message minus the time span that passed beginning with A hearing from B the last time and ending with A sending a message to B. Confer to the slide "What's up with rtt-idle".	[2696-((3400-1200)-(2000x0.92/1.08)), 2888-0] = [2696-(2200-1704), 2888-0] = [2400, 2888]

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Exercise 8.3: Estimation of a time interval with uncertainty

b) In the above mentioned scenario A informs B about events over a long period however, B has no reason to communicate with A and thus only receives data. In this context collisions on the radio channel are not considered. What is the problem here and how can it be solved?

Solution:

In order to determine the packet delay from node B to A and back the NTP-like ping-message can be used which is responded by a pong-message. In sensor networks these additional packets, which cause no problems in wired networks, should be avoided. Therefor, the time of the arrival of the last message can implicitly be interpreted as the ping-message from NTP and the next message being send (for application specific reasons) can at the same time be “misused” as a pong-message.

In general, if one node always sends messages in a one-way scenario those messages can be considered as repeated pong-messages of NTP which always reuse the single former ping from the receiving node. After a while the time span between the two types of messages can become too large so that the accumulating errors of the clocks are sooner or later in the order of magnitude of the round trip time itself.

In this case an extra message has to be send from the receiving node, even if there is no need for a message on the application level.

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Exercise 8.4: RBS vs. RTT basiert

In order to determine the drift of clocks the Reference Broadcast Synchronization (RBS) or the NTP-like round trip time based approach can be used. Decide which model is the better one based on the following assumptions:

a) There are no errors other than the access time to the medium. But the access time has a high variance.

Solution:

RBS is the better choice here because the access time to the medium evolves at the synchronizer. But in RBS the time of arrival of the signal at the nodes is important. It is not interesting what happened before. Note that the error-estimate for the RBS-based drift does not include any latencies on the sender side.

b) There is no other error than the access time to the medium. The access time is unknown and the same for all nodes and it is known that it has no variance.

Solution:

There is no difference between RBS and RTT based synch approaches. In the expressions below e_2 does not even contain any access time. e_1 does include it but it drops out as A_A and A_B have no variance (so their expectation value is always met).

$$e_1 = \frac{S_A + A_A + R_B - S_B - A_B - R_A}{2} \qquad e_2 = P_{S,A} + R_A - P_{S,B} - R_B$$

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Exercise 8.4: RBS vs. RTT basiert

In order to determine the drift of clocks the Reference Broadcast Synchronization (RBS) or the NTP-like round trip time based approach can be used. Decide which model is the better one based on the following assumptions:

c) Only the time for receiving a packet is not negligible. The deterministic reception time is different for every node but it is known.

Solution:

In RBS the reception delays are contained in the error estimate but they drop out if both of them are equal. The same is true for RTT based synchronization. Since the reception delays (denoted with R_{index}) are not the same for every node they do not drop out in general.

Both approaches are equally suited.

d) The only influence is the signal propagation time (of acoustic signals of the synchronizer) and the locations of the nodes are unknown.

Solution:

In the RTT based synchronization the time a signal travels from A to B is equal to the time is needs on the reverse path so these delays are vanishing. In RBS two nodes can have different distances to a synchronizer so the time the signal travels between two different nodes is not the same in general. In this case RTT is more suitable than RBS.

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Exercise 8.5: RBS

The drift between two nodes A and B should be determined using RBS. These two nodes are the only ones available. So one node chooses to be the synchronizer and sends the sync signal. Which inaccuracy is caused in this situation as compared to using a central node? For what reason is a central synchronizer essential?

Solution:

Here node A synchronizes node B. Basically A could trigger itself and B would be triggered by the arriving sync signal. However, all kinds of delays which B experiences are missing on A's side, e.g., the access time A_A to the medium or the reception time R. Maybe some errors could be simulated, e.g., S_A by taking the time in the moment the first bit leaves node A. But the reception time R and the signal propagation time P can not be simulated easily. However, RBS hopes that the delays at different receivers are about the same order of magnitude and thus cancel out each other.

By using a central node all receivers are in the (more or less) same situation. This is not true if a node is the synchronizer itself.

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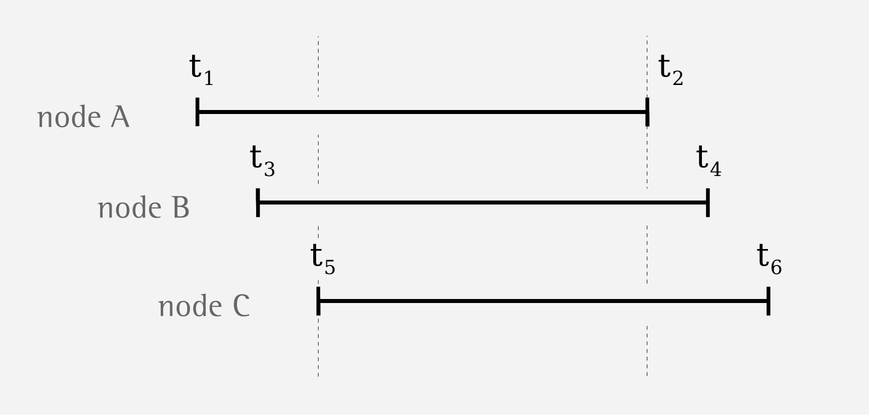
Exercise 8.6: Comparison of fuzzily determined events

An event A takes place in the time interval [t1, t2], another event B in [t3, t4] and the event C in [t5, t6]. The following holds true: t1 < t3 < t5 < t2 < t4 < t6. What is the probability that C happens first, than B and A at last.

Solution:

Let's obtain the probability that every event takes place in the interval [t5,t2]. This is a precondition that the events can take place in the order C, B, and A.



Node A $\frac{t_2 - t_5}{t_2 - t_1}$

Node B $\frac{t_2 - t_5}{t_4 - t_3}$

Node C $\frac{t_2 - t_5}{t_6 - t_5}$

Probability that all events happen in [t5,t2].

$$(t_2 - t_5)^3 \times \left[(t_2 - t_1)(t_4 - t_3)(t_6 - t_5)\right]^{-1}$$

The events can be ordered in 6 configurations but only one is valid in this context:

$$\frac{(t_2 - t_5)^3 \times \left[(t_2 - t_1)(t_4 - t_3)(t_6 - t_5)\right]^{-1}}{6}$$