Performance Comparison of Asynchronous Ranging Algorithms

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Findings

Finding 1

- Ranging time is an important attribute in designing a ranging algorithm or a location positioning system
- Ranging time affects the real-time operation, battery lifetime, and system scalability of a location positioning system

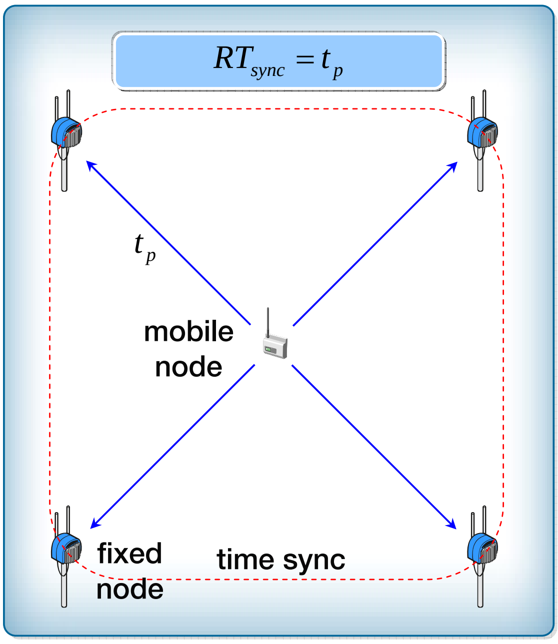
Finding 2

- SDS-TWR-MA provides the best compromise between ranging accuracy and total ranging time when we hope for more accurate and stable ranging results
- SDS-TWR-MA algorithm is suitable for the real-time location positioning system

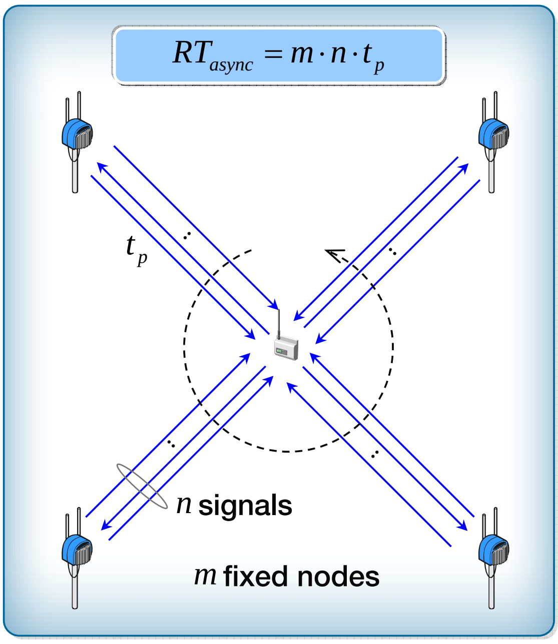
Motivation

To Reduce the Long Ranging Time in the Asynchronous Ranging Scheme

Synchronous Ranging Scheme



Asynchronous Ranging Scheme



Taxonomy of Ranging Methods

Ranging Algorithm

- **Time-based Ranging**
  - **Synchronous**
    - Fixed nodes are time-synchronized.
  - **Asynchronous**
    - Fixed nodes are not time-synchronized.
- **RSS-based Ranging**
  - **Synchronous**
    - Rigid time synch is not required.
  - **Asynchronous**

Ranging Algorithm

- **Network-based Ranging**
  - Mobile nodes transmit beacon signals periodically and fixed nodes extract ranging information (time or strength) from them.
- **Terminal-based Ranging**
  - Fixed nodes transmit beacon signals periodically and a mobile node extracts ranging information from them. Mobile nodes could compute their location by themselves.

Synchronous Ranging Scheme

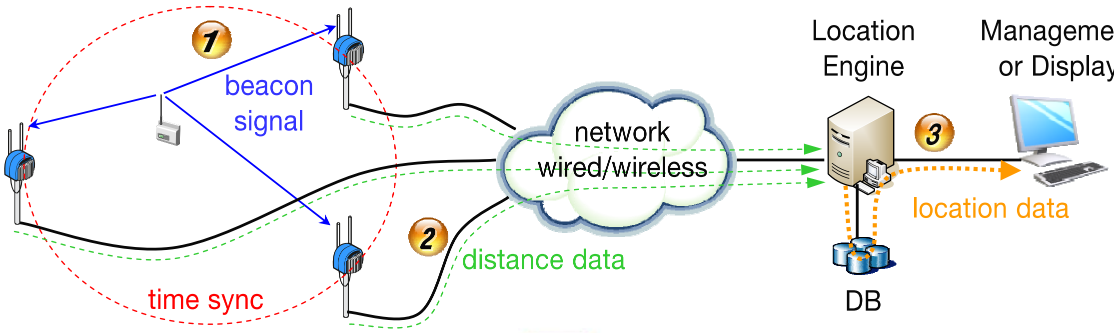
Operation and Attributes

Operation

- All fixed nodes have to be synchronized to one another.
- Mobile nodes broadcast beacon signals periodically.
- Fixed nodes which received the beacon signals calculate the flight time of the beacon signal. (flight time ➲ distance)

Attributes

- Ranging time is very short: less than 1 msec.
- Locating time is equal to ranging time. (w/o processing time)
- **Requires complex circuitry for the global time synch.**
- **Requires a precise and expensive oscillator.**
- **Limited scalability due to the synchronization issue.**



Asynchronous Ranging Scheme

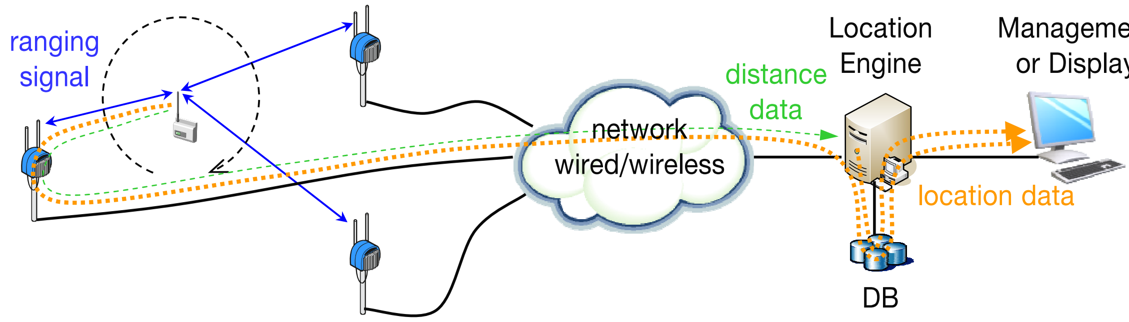
Operation and Attributes

Operation

- All fixed nodes don't need to be synchronized ➲ *scalable*
- For a location estimation, each mobile node has to exchange couples of ranging signals in a sequential manner ➲ *long ranging time*
- Usually, mobile nodes calculate distances from each fixed node and, sometimes, estimate their location.

Attributes

- Ranging time is comparatively long: less than 10 msec.
- **Locating time is much longer than ranging time. (~50msec)**
- Does require neither complex circuitry for the global time synch nor a precise and expensive oscillator ➲ *cheap and practical*

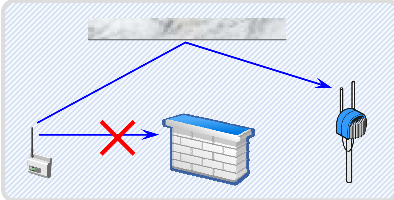


Ranging Error (Locating Error)

Ranging results may differ from real distance

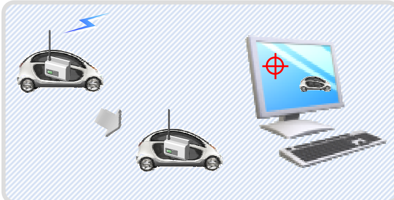
- due to *Environmental Factors* :

The estimated distance is variable
due to such environmental factors as
reflection, refraction, interference, multipath, etc,
even though the mobile node is not moving.



- due to *Processing Delay* :

It takes time to handle the ranging process and
the location calculation. For moving mobile nodes,
the estimated distance or location is
the distance or location of the past, not right now.

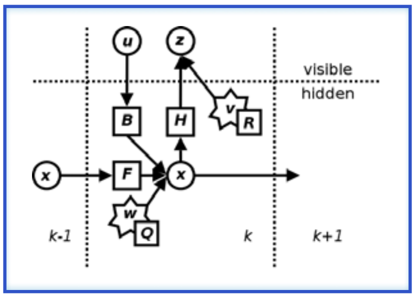


- due to *other factors* such as clock offset, clock drift, and so on.

For More Accurate Ranging Results

Efforts to Improve the Ranging Accuracy

- Use a filtering algorithm
  - When a unrealistic measurement is obtained, it can be trimmed to be within normal range.
  - ex) The maximum moving distance for human can be set to 5m/s. If a measured value is 7, it is adjusted to 5.
- Use a estimation algorithm
  - Current location is estimated by reflecting the moving pattern of the object under test.
  - ex) Kalmann filtering



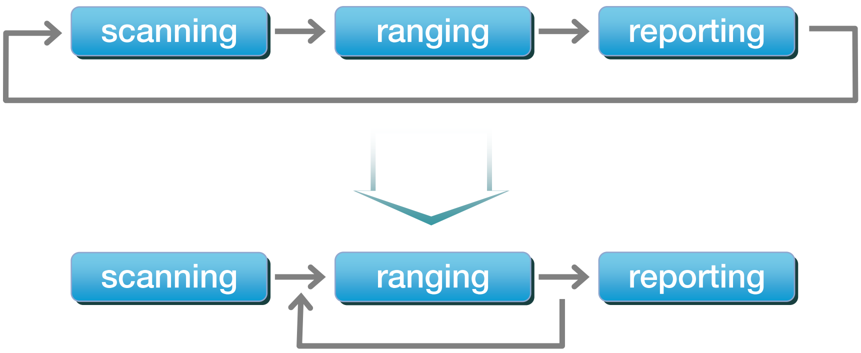
〈 Kalmann filtering 〉

- Deploy more fixed nodes
  - Ranging error can be caused by obstacles such as wall, furniture, human body, etc.
  - Additional fixed nodes possibly reduce the effect of these obstacles.
  - It is a bit practical approach, but it cost much.
- Repeat ranging measurement ➲ *adopted in practice*
  - Environmental effects, which is instantaneous, could be mitigated by multiple measurements.
  - However, this approach requires much time and power consuming.

For More Accurate Ranging Results

Efforts to Improve the Ranging Accuracy

- Repeat the distance measure multiple times



- A ranging process is composed of three phases: scanning phase, ranging phase, and reporting phase.
- Repeating a ranging process implies repeating all these phases.
- Among these three phases, repeating scanning and reporting phases are redundant when we repeat a ranging process several times.

Single-Sided Two-Way Ranging (SS-TWR)

SS-TWR

- Single-Sided Two-Way Ranging was designed to remove the requirement of global time synchronization.
- However, the ranging result could be affected by factors of fixed nodes such as clock drift and clock offset.
- Ranging error (accuracy)

$$t_{RE} = \frac{1}{2}(e_A - e_B)\cdot t_{replyB}$$

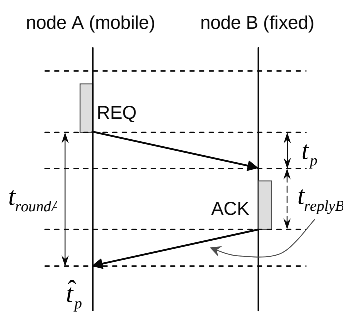
- Ranging time

$$t_{range1} = 2\cdot t_{reply}$$

- Ranging time when we iterate it n times

$$t_{range1} = 2n\cdot t_{reply}$$

SS-TWR Procedure



Nomenclature

- t_{RE}: ranging error
- t_{range}: ranging time
- t_{roundA}: round-trip time at node A
- t_{replyB}: processing time at node B
- e_A and e_B: the influence of factors at node A and node B, respectively

Symmetric Double-Sided Two-Way Ranging (SDS-TWR)

SDS-TWR

- SDS-TWR was devised to solve the ranging error caused by systematic factors with SS-TWR.
- However, it doubles the ranging time.
- Ranging error (accuracy)

$$t_{RE} = \frac{1}{4}(e_A - e_B)\cdot(t_{replyB} - t_{replyA})$$

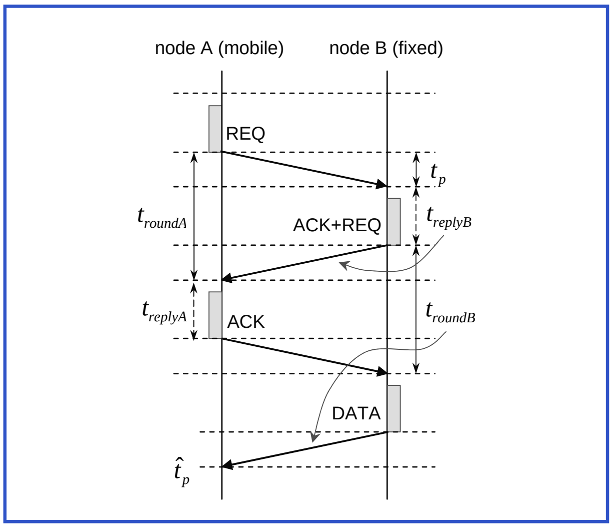
- Ranging time

$$t_{range2} = 4 \cdot t_{reply}$$

- Ranging time when we iterate it n times

$$t_{range2} = 4n \cdot t_{reply}$$

SDS-TWR Procedure



Assumption

- Here, we assume that ranging results are sent by mobile nodes not by fixed nodes.
- Assuming that fixed nodes transmit ranging result, the last packet is not required.

SDS-TWR Multiple Access (SDS-TWR-MA)

SDS-TWR-MA

- Use multiple acknowledgement packets for a single ranging request
- It solves the problems of long ranging time inaccuracy due to asymmetry
- Ranging error (accuracy)

$$t_{RE} = \frac{1}{4}(e_A - e_B)\sum_{i=1}^{n}(t_{replyBi} - t_{replyAi})$$

- Ranging time for an ACK+REQ pkt

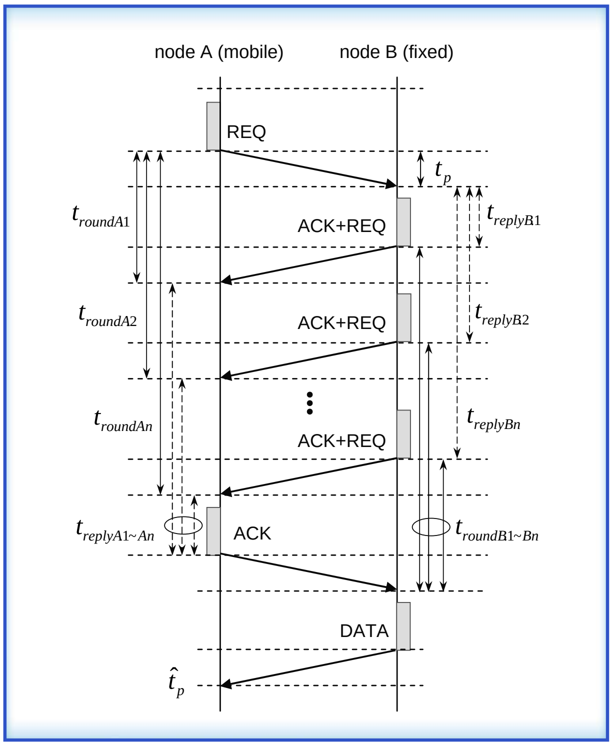
$$t_{range3} = 4 \cdot t_{reply}$$

- Ranging time for multiple (n) number of ACK+REQ packets

$$t_{range3} = (n+3)\cdot t_{reply}$$

- When $n=1$, SDS-TWR-MA is identical to SDS-TWR

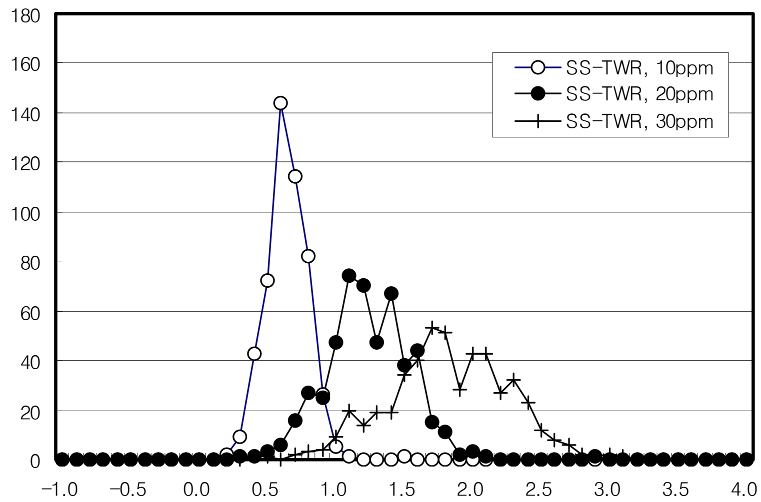
SDS-TWR-MA Procedure



Performance Evaluation – Ranging Accuracy

Ranging Error of SS-TWR

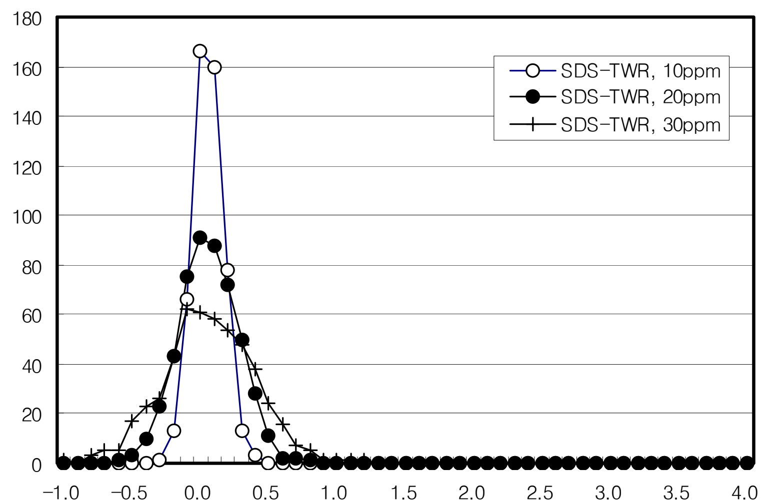
- Ranging errors are distributed around larger mean values as clock offset values.
- We can get a more accurate result by adjusting the ranging result as much as mean ranging error. (0.59m, 1.18m, and 1.78m for 10ppm, 20ppm, and 30ppm)



Performance Evaluation – Ranging Accuracy

Ranging Error of SDS-TWR

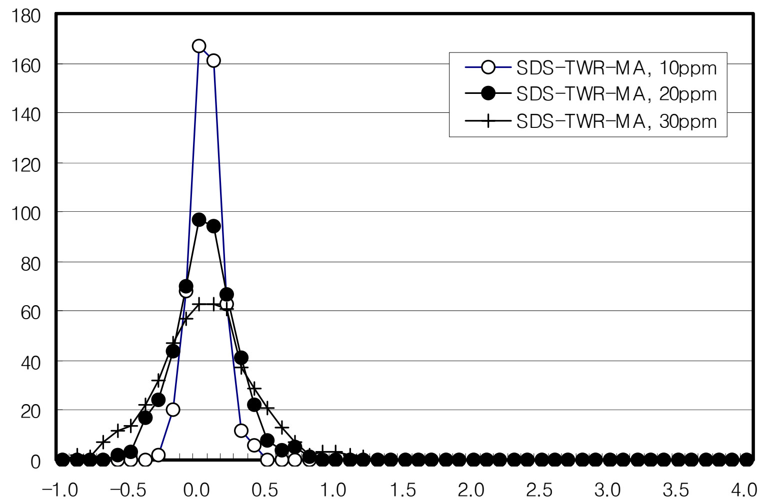
- Ranging errors are centered around 0m, irrespective of the clock offset values.
- Symmetric feature of SDS-TWR gets rid of the effect of systematic factors.
- If we repeat SDS-TWR several times, we can more an accurate and stable result.



Performance Evaluation – Ranging Accuracy

Ranging Error of SDS-TWR-MA

- Ranging errors are centered around 0m, irrespective of the clock offset values.
- In terms of ranging error/accuracy, we can not tell SDS-TWR-MA from SDS-TWR.
- However, it requires much less time in completing the ranging process.



Performance Evaluation – Ranging Accuracy

Comparison of Ranging Error

- The maximum ranging error decreases gradually as the iteration times increases.
- The mean and the standard deviation of ranging error is small enough for SDS-TWR and SDS-TWR-MA, even though the clock offset value is 30ppm.
- The mean ranging error of SS-TWR was almost constant to 2.3m, 4.5m, 6.8m for the clock offset values of 10, 20, and 30ppm.

Maximum ranging error for different iteration times

iteration (n)	1	2	3	4
SDS-TWR	3.68m	3.35m	2.82m	2.32m
SS-TWR	8.90m	7.58m	6.92m	6.52m
SDS-TWR-MA	3.64m	3.34m	2.93m	1.88m

- Norman Distribution $N(1500, 500^2)$
  - 500 trials for each simulation
  - clock offset value = 20ppm

- Values for SDS-TWR-MA
  - mean ranging error ~ 0.0m
  - stardard deviation ~ 0.4m

Performance Evaluation – Total Ranging Time

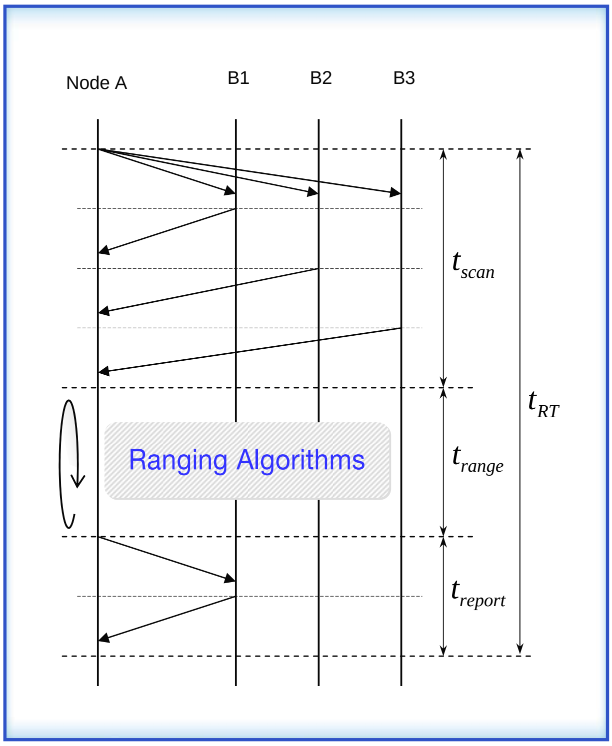
Location Positioning Procedure

- Total Ranging Time (t_{RT})

$$t_{RT} = t_{scan} + t_{range} + t_{report}$$

- The scanning phase and the reporting phase are considered to be the same for the three ranging algorithms.
- The scanning time is usually fixed, considering the number of maximum allowable nodes which could take part in the ranging procedure.

▪ **Assumptions**
- 3 fixed nodes are used
- $t_{replyA} = t_{replyB} = t_{reply}$
- t_p is much smaller than t_{reply}



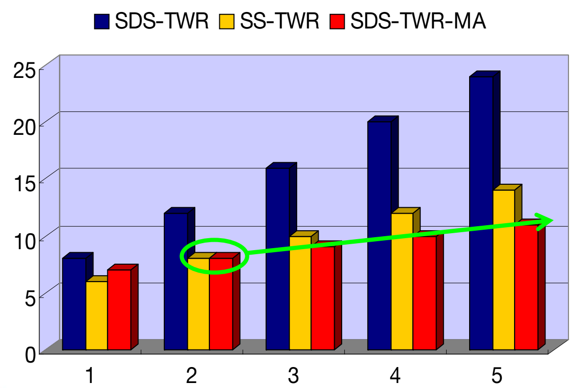
Performance Evaluation – Total Ranging Time

Total Ranging Time

	SS-TWR	SDS-TWR	SDS-TWR-MA
Scanning Time	$t_{scan} = 4t_p + 3t_{replyB} \approx 3t_{reply}$		
Ranging Time	$t_{range1} = 2n \cdot t_{reply}$	$t_{range2} = 4n \cdot t_{reply}$	$t_{range3} = (n+3) \cdot t_{reply}$
Reporting Time	$t_{repot} = 2t_p + t_{replyB} \approx t_{reply}$		
Total Ranging Time	$t_{RT.1} = 2(n+2) \cdot t_{reply}$	$t_{RT.2} = 4(n+1) \cdot t_{reply}$	$t_{RT.3} = (n+6) \cdot t_{reply}$

Total Ranging Time

iteration	SDS-TWR	SS-TWR	SDS-TWR-MA
1	8	6	7
2	12	8	8
3	16	10	9
4	20	12	10
5	24	14	11



Performance Evaluation – Total Ranging Time

Major Findings are …

- Ranging time is as important as ranging accuracy!!
- SDS-TWR-MA provides the best compromise between ranging accuracy and total ranging time

Short Ranging Time means …

- The ranging algorithm is suitable for real-time locating systems
- Longer battery lifetime by consuming power in a shorter period
- Locating system could be scalable
  - It is because a fixed node can communicate more mobile nodes when the total ranging time is short.
  - Please refer to other papers published by me.

Our Contribution is …

- We focus on the importance of the ranging time for the first time!!