CRIT：A Hierarchical Chained-Ripple Time Synchronization in Wireless Sensor Networks

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Introduction(1)

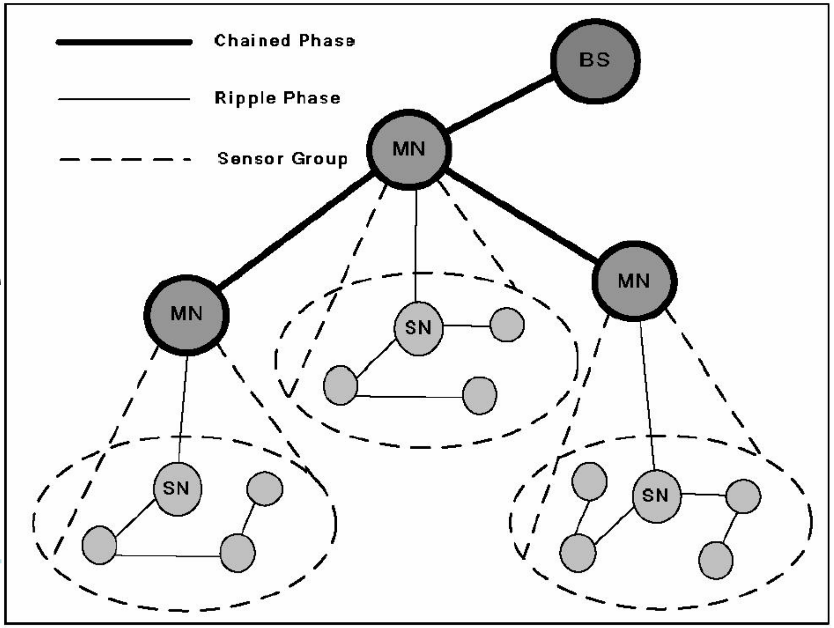
- Time synchronization is a essential problem in wireless sensor networks.
- A lot of operation needs it.
  - Data aggregation
  - TDMA schedules
  - Synchronized sleep
  - Periods
- Most of time synchronization methods in traditional internet and wireless LAN do not consider the limited resourced and energy available.

Introduction(2)

- The author proposed a flexible Chained-Ripple Time Synchronization(CRIT) protocol.
- This protocol uses a hierarchical and multi-hop architecture suitable for WSN.

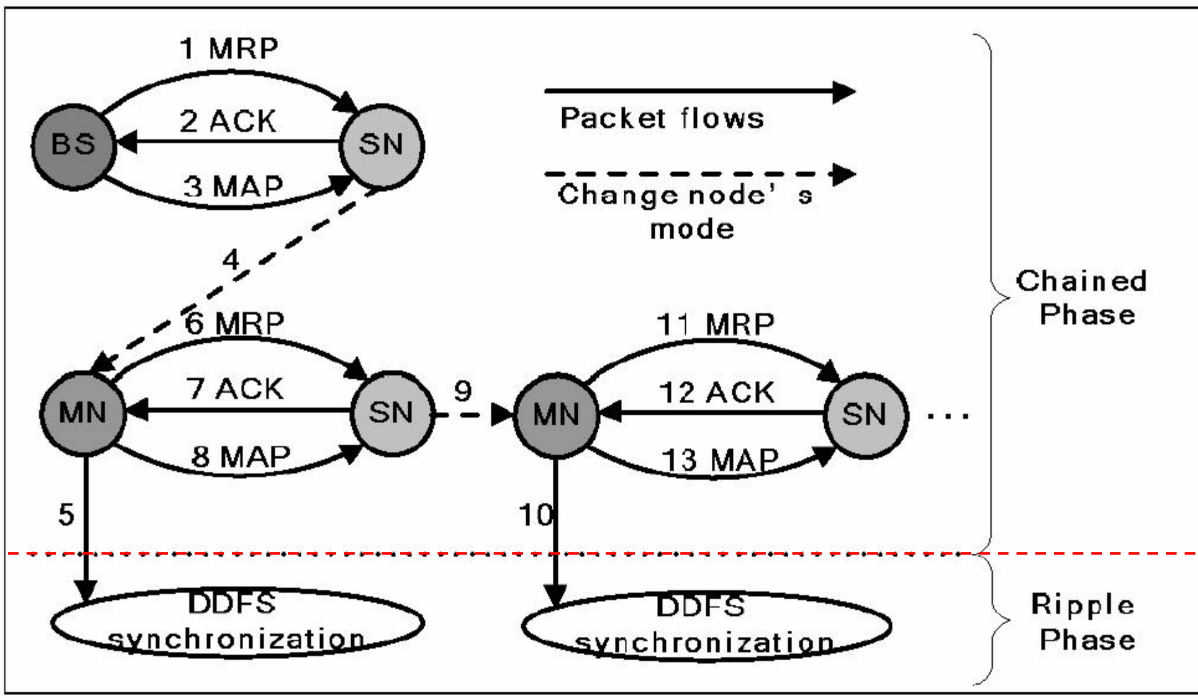
Network Architecture

- Base Station (BS)
  - This is an original time resource node.
  - The BS has stronger radio transmission capability.
- Missionary Node (MN)
  - A MN is selected by the BS or another MN of neighboring group.
  - A MN has own sensor group(SG).
- Sensor Node (SN)
  - We assume that SNs locates in intersect area of SGs only formulate a communication with a MNs.



Chained-Ripple Time Synchronization

- The proposed algorithm is divided into the two phases:
  - Horizontal Missionary Node Discovery Phase (Chained Phase)
  - Vertical Sensor Node Synchronization Phase (Ripple Phase).

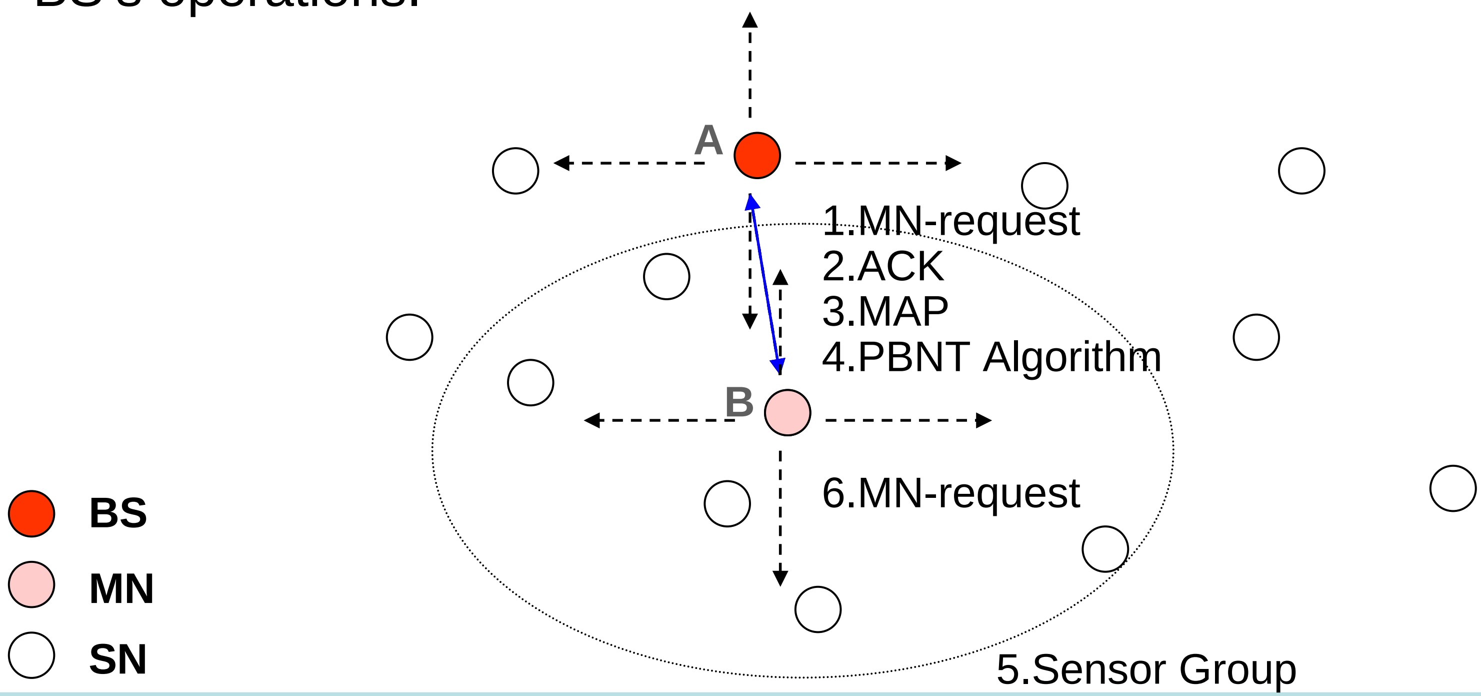


Chained Phase(1)

- When the BS has been setup for time synchronization in WSN, Chained Phase starts.
  - The BS initially broadcasts MN-REQUEST packet (MRP) through the network for assigning a MN.
  - When a normal SN that wants to be a MN receives the MRP, it sends acknowledgement (ACK) packet with own piggybacked clock information to the BS.
  - The BS receives this ACK packet and resends MISSIONARY-ASSIGN packet (MAP) with own piggybacked clock information to the SN.
  - The SN receiving this MAP becomes a MN in WSN and adjusts own clock information by Piggy-Back Neighbor Time Synchronization (PBNT) algorithm.

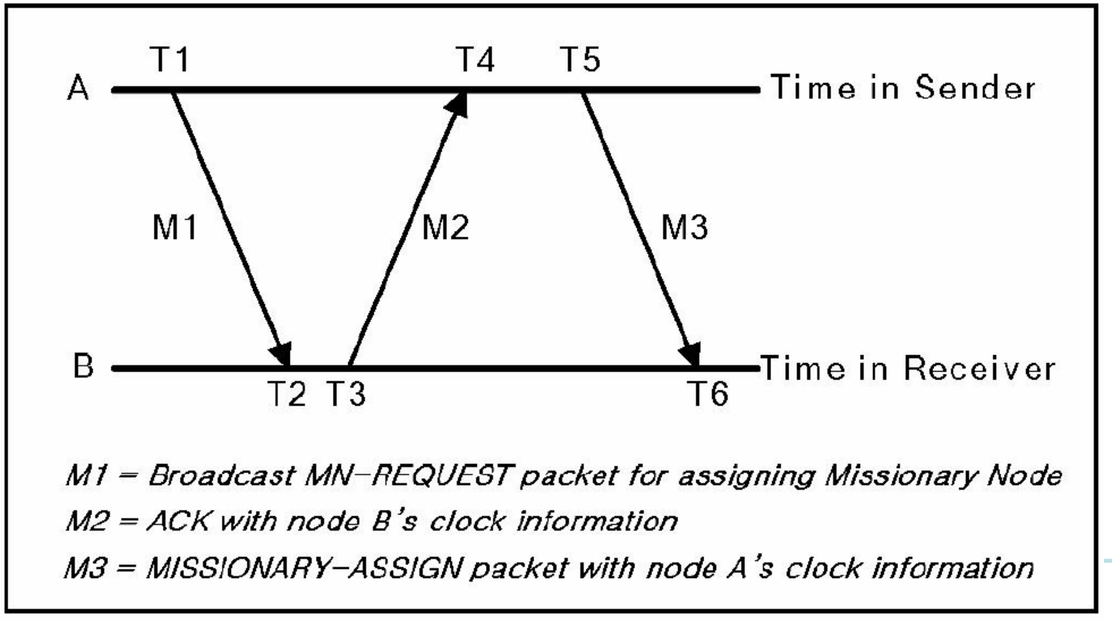
Chained Phase(2)

- The MN constructs a SG with neighbor SNs by RipplePhase mechanism.
- The MN broadcasts a MRP for assigning other MNs same as the BS's operations.



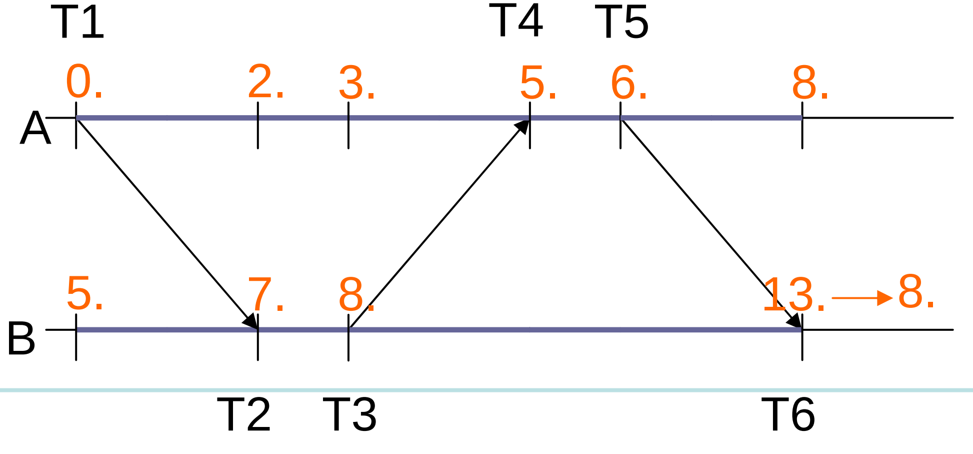
Piggy-Back Neighbor Time Synchronization(PBNT)

- At T1, node A broadcasts a MRP (M1).
- At T2, after node B receives this MRP, node B waits for some random time (T3 ~T2).
- At T3, node B sends ACK packet in response to the MRP with own piggybacked clock information (M2) to node A.



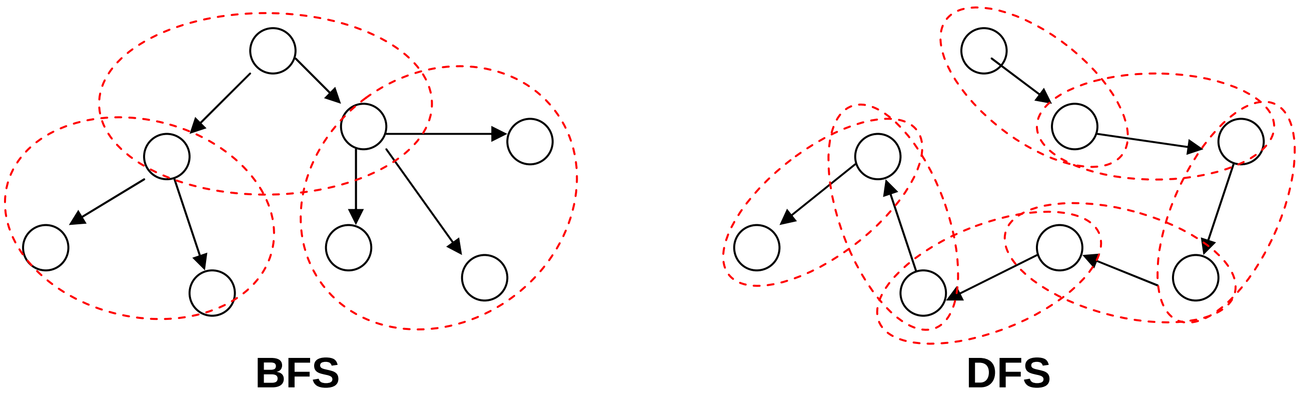
PBNT(2)

- At T4, node A receives this ACK packet.
- At T5, node A sends back a MAP with own piggybacked clock information (M3) to node B.
- At T6, after node A receives the packet, node A calculates clock offset(o) and propagation delay(d) as follows：
  - o = [(T4-T3) - (T6-T5)] / 2
  - d = [(T4-T3) + (T6-T5)] / 2



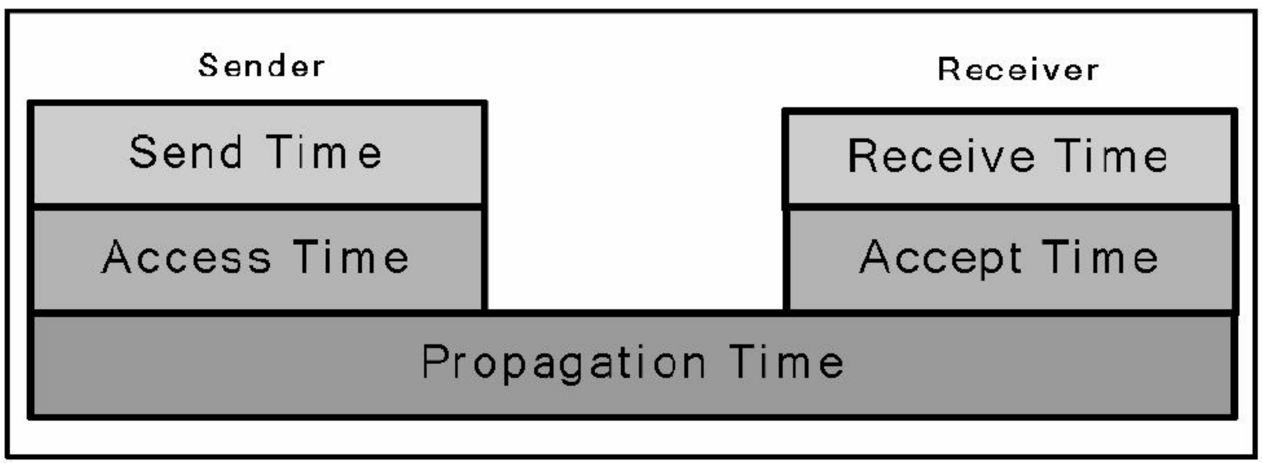
Ripple Phase

- All SNs in each SG efficiently synchronize to each other with a MN by Distributed Depth-first-Search(DDFS) algorithm.
- At T6, the node B formulates a DDFS communication link with neighbor SNs and sends its clock information packet.
- Through this clock information packet, each SN can efficiently tune up own clock information.
- The communication and time complexities is O(|N|), where N is the number of node, DDFS algorithm maximized time synchronization accuracy.



Error Analysis of CRIT(1)

- Sources of time synchronization error
  - Send time
  - Access time
  - Propagation time
  - Accept time
  - Receive time



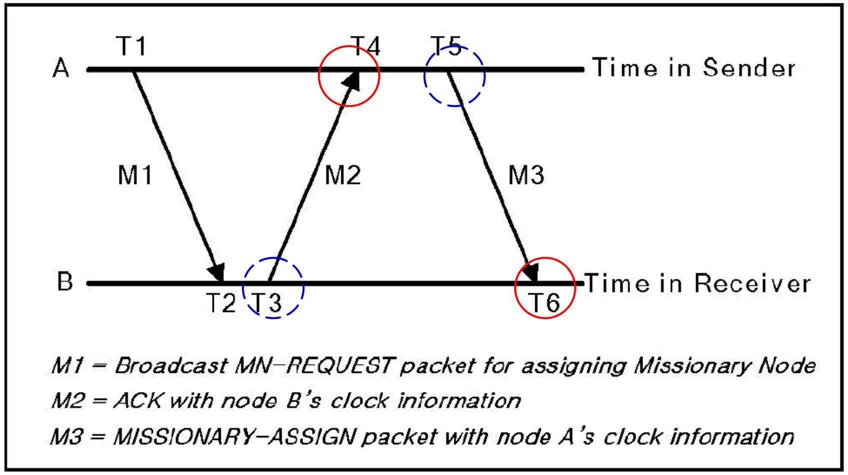
Error Analysis of CRIT(2)

$$T_4 - T_6 = a_{T_3}^{B\to A} T_3 - (a_{T_3}^{B\to A} + \boxed{ra_{T_3\to T_5}}) T_5 + O_{T_3}^{B\to A} - (O_{T_3}^{B\to A} + \boxed{ro_{T_3\to T_5}}) + \boxed{D}$$

$$S_D + AS_D + P_D + AC_D + R_D = D$$

$$a_{T_5}^{A\to B} = a_{T_3}^{B\to A} + ra_{T_3\to T_5}$$

$$O_{T_5}^{A\to B} = O_{T_3}^{B\to A} + ro_{T_3\to T_5}$$



- We knows from equation that relative clock drift , relative clock offset, and D are critical elements.

Error Analysis of CRIT(3)

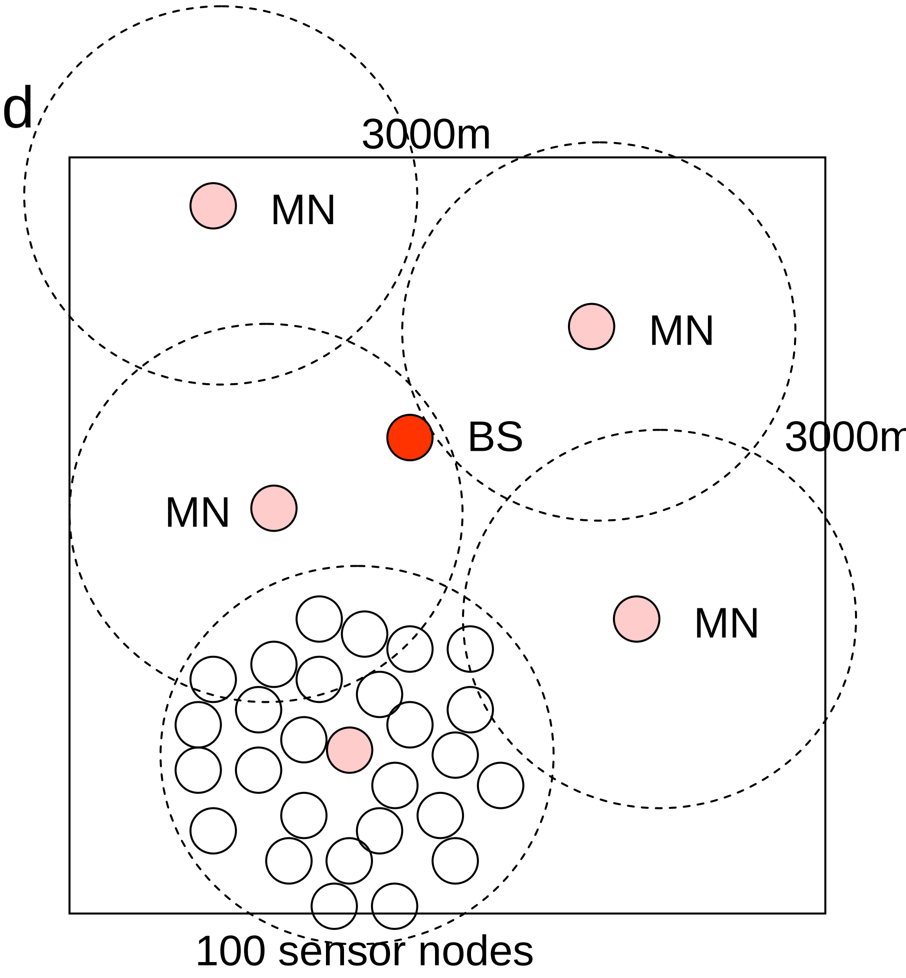
$$Chained\ Phase\ Error = \frac{1}{n}\sum_{i=1}^{n}\{ra_i + ro_i + D_i\}$$

- Because time synchronization of Ripple Phase using DDFS algorithm is dependent on node's counts in each SG, we regard its time synchronization error rate as O(n), *n* is the number of nodes.
- We can also appear a synchronization error equation of CRIT with maximum and minimum rate.

$$\underline{CRITError} \leq \frac{1}{n}\sum_{i=1}^{n}\{ra_i + ro_i + D_i\} + O(n) \leq \overline{CRITError}$$

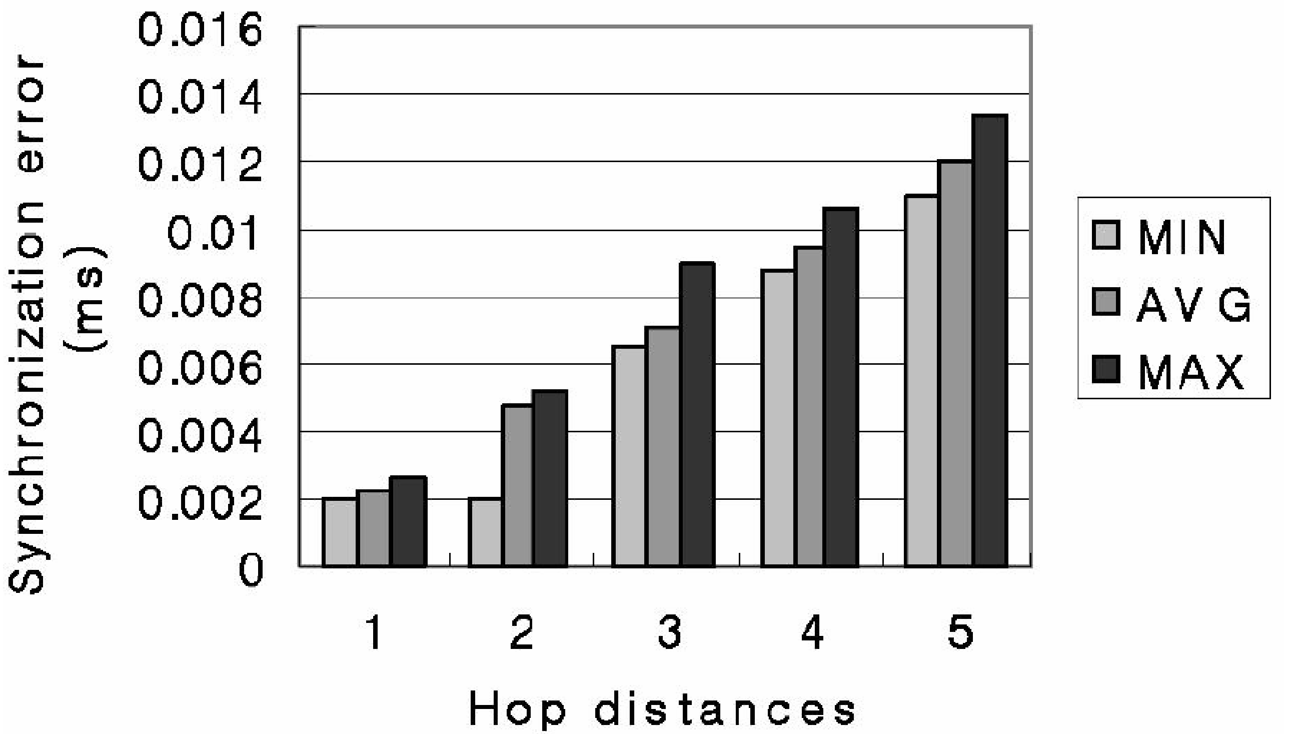
Performance Evaluation

- Synchronization error of Chained Phase
- Synchronization error of Ripple Phase
  - According to the number of SNs in each SG.
- Clock offset:
  - An average of all nodes' clock offsets compared with the BS's local time in each SG.



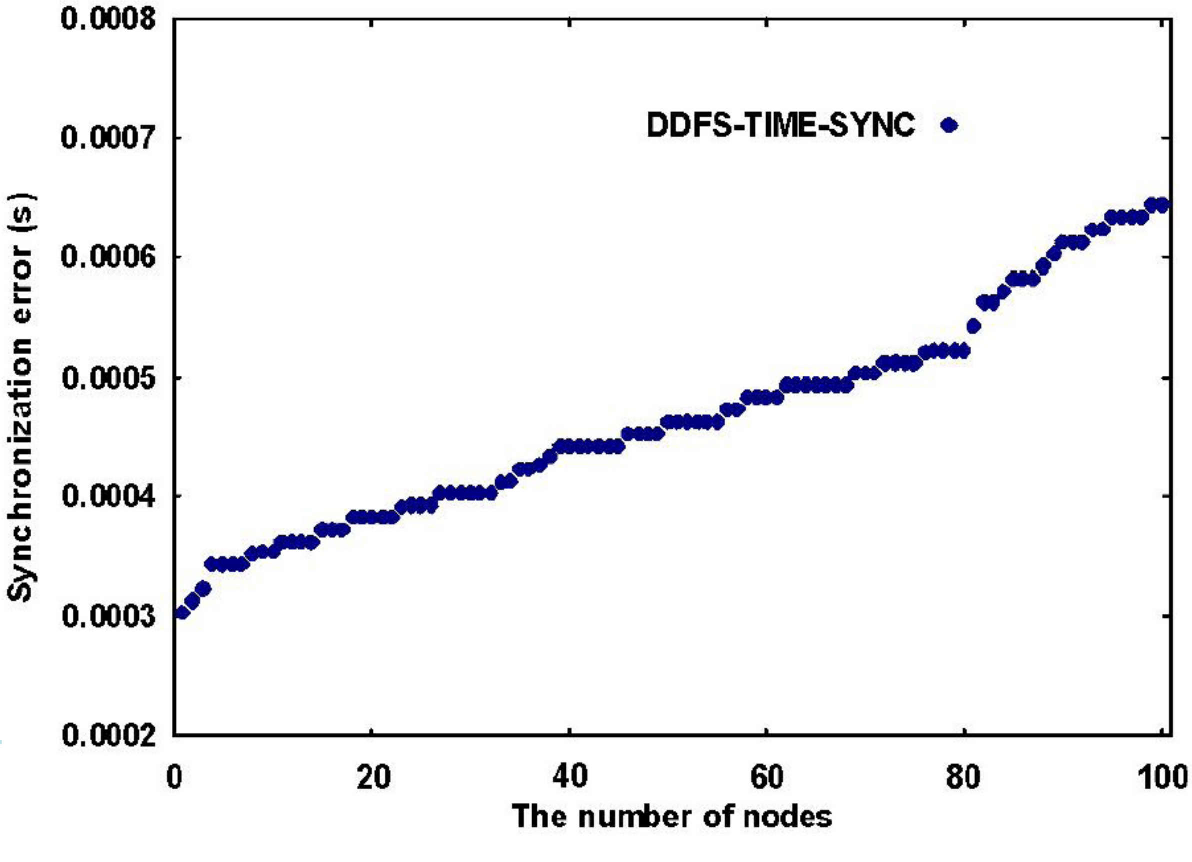
Synchronization error of Chained Phase

- The increasing amount is very slight because the PBNT algorithm used the piggybacked time information mechanism for reducing communication overhead.



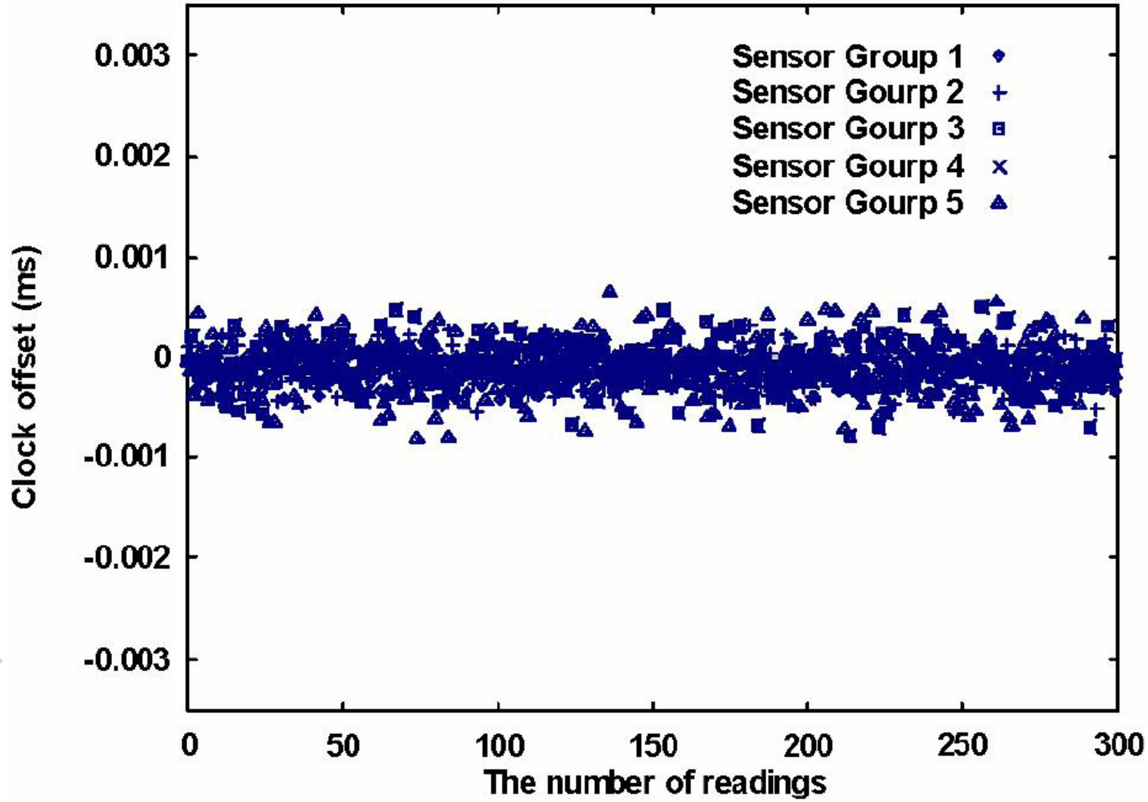
Synchronization error of Ripple Phase

- DDFS algorithm has the communication and time complexity with O(n), where n is the number of node, it is certain that synchronization error increases according to the number of nodes.



Clock Offset

- We evaluated the average clock offset of all nodes in each SG compared with the BS's local time.
- The clock offset values keep near constant zero according to the number of reading after 1000s of simulation.



Conclusion

- The author introduced a fast, flexible, and high precise time synchronization mechanism with considering the energy-efficient problem in WSN.
- CRIT contributes in the accurate hierarchical and multi-hop time synchronization with low error-rate and efficient clock offset.