# Runtime Control of LoRa Spreading Factor for Campus Shuttle Monitoring

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# Motivation

BINGHAMTON UNIVERSITY
State University of New York

- *Project goal: Building a low-cost system for data collection from six shuttles that circle our university campus to enhance safety and efficiency of shuttle service*

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  - *Vehicle speed => Expected time of arrival (ETA)*
  - *Number of passengers => Transit demand*
  - *Vehicle's operating condition => Maintenance warnings*

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- *Two types of data*
  - *Time-critical data: vehicle speed, the number of passengers, etc.*
  - *Non-time-critical data: vehicle's engine and braking performance, etc.*

# Available Wireless Technologies



- Several wireless technologies are readily available today

| Technologies | Cost | Link Distance | Coverage |
|---|---|---|---|
| Wi-Fi | Low | Short | Poor |
| Satellite | High | Long | Good |
| Cellular | High | Long | Good |
| LoRa | ***Low*** | ***Long*** | ***Good*** |


# LoRa

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- LoRa (**Lo**ng **Ra**nge): a low-power wide-area network (LPWAN) technology
  - Cost-effective: inexpensive devices that use free ISM frequency bands
  - Long-range: a single base station that covers the entire university campus
  - Low-power: battery-powered modules easily and inexpensively retrofit sensors on shuttles



# Hardware Deployment



- Using inexpensive COTS devices
  - A star network with a single base station
- *LoRa base station*
  - *Raspberry Pi + iC980A module*
  - *In a weatherproof box on the roof of a three-floor building*

# Hardware Deployment

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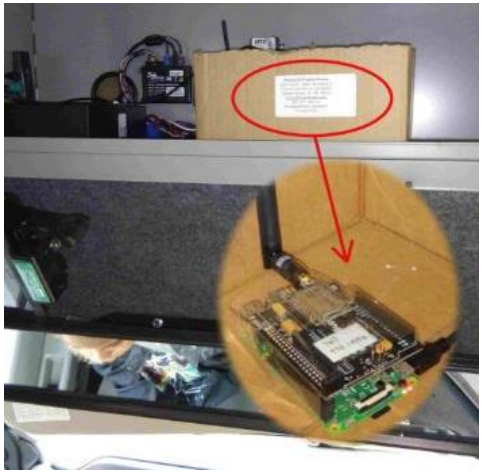
  - A star network with a single base station
- LoRa base station
  - Raspberry Pi + iC980A module
  - In a weatherproof box on the roof of a three-floor building
- LoRa end device
  - Raspberry Pi + RN2903 module
  - In the glove compartment of the shuttle
- **Total hardware cost: $536**



# Challenge of SF Configuration

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- LoRa spreading factor (SF): a physical-layer parameter

- Tradeoff between reliability and throughput
  - Maximum data rate is proportional to (sf / 2^sf)
  - Theoretical required SNR to decode a packet: (12 – sf) * 2.5 – 20 (dB)
    - SF7: shortest link distance, highest throughput
    - SF12: longest link distance, lowest throughput

- Empirical study on the impact of SF configuration on network performance
  - LoRa end device uses all SFs (SF7 to SF12) in a round-robin fashion
  - Collected 3.18 million measurements during shuttles' real-world operations over 14 months

# Empirical Study on SF Configuration

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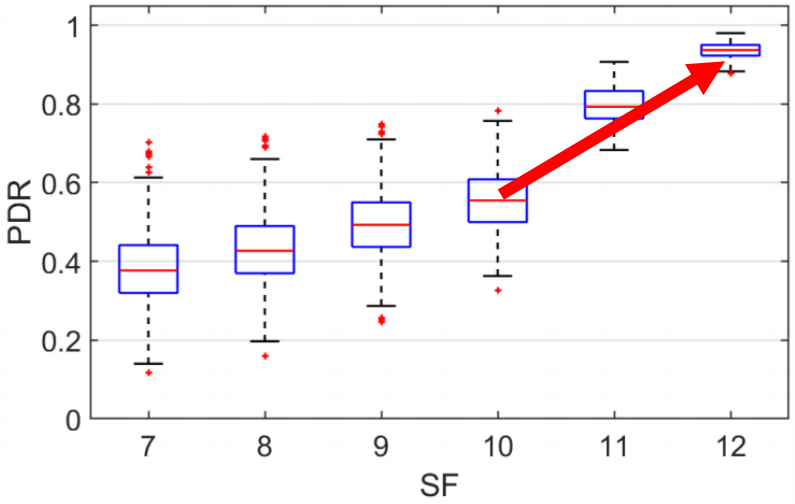
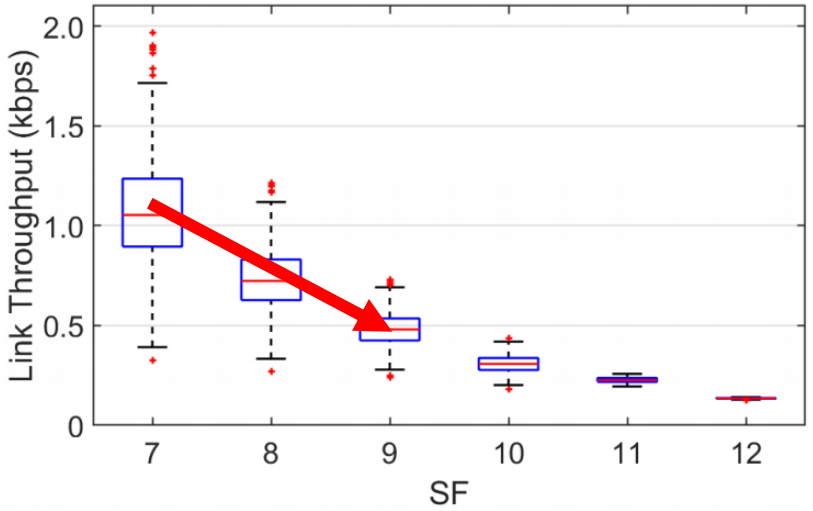
  - Used all SFs (SF7 to SF12) in a round-robin fashion
  - Collected 3.18 million data samples over 14-month real-world operations




***PDR increases at the cost of decreased throughput when using a larger SF***

# Empirical Study on ADR

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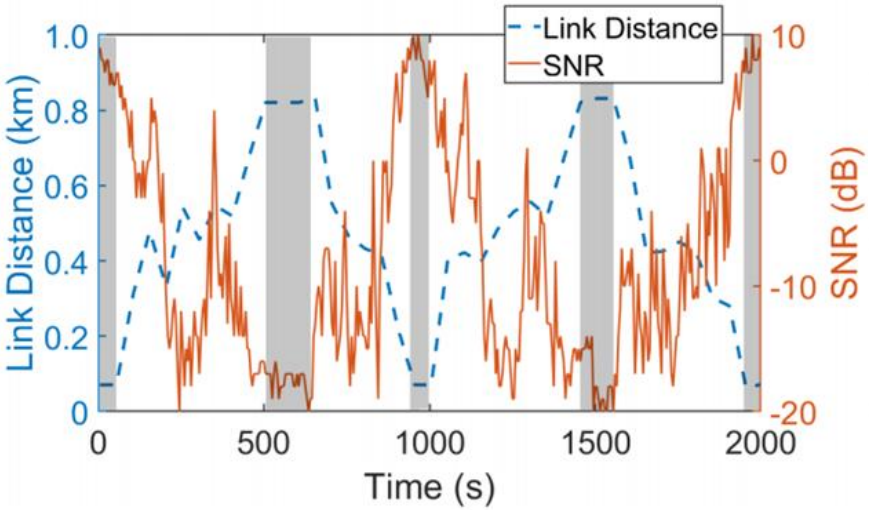
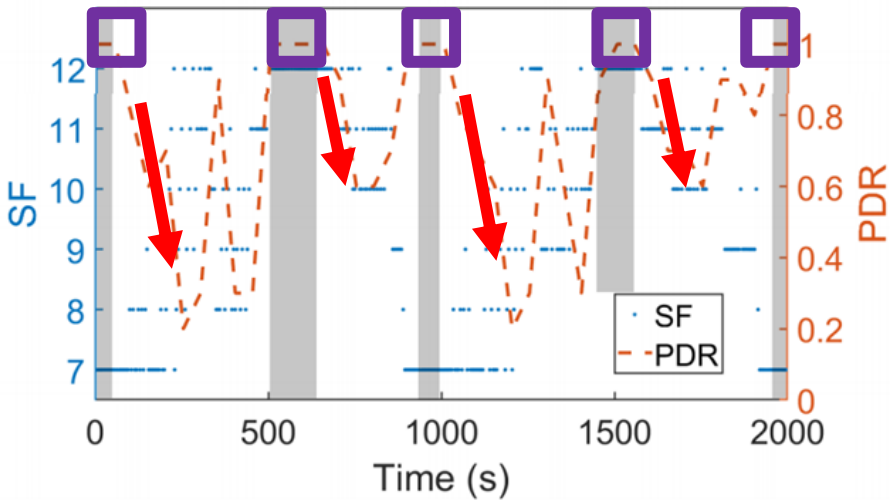
- Adaptive Data Rate (ADR) specified in LoRaWAN: an algorithm that selects SF based on link quality measurements
- A data trace that shows the link reliability changes when a shuttle circles the campus twice



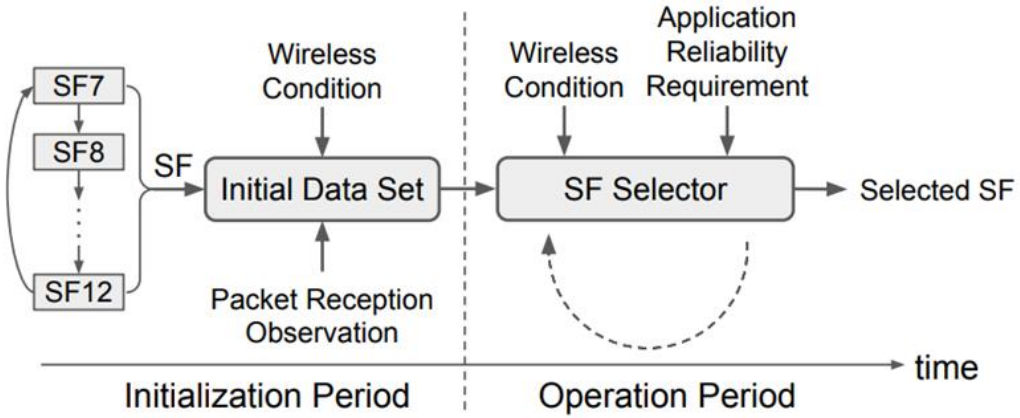




***ADR is ineffective when the LoRa end device is in motion***

# Runtime SF Control Solution



- Design goals
  - 1st priority: meet the link **reliability** requirement specified by the application
  - 2nd priority: maximize data collection **throughput**
- Input
  - Runtime wireless link quality measurements
  - Reliability requirement
  - Initial data set
- Two periods
  - Initialization and Operation



# Runtime SF Control Solution



- SF selector with K-Nearest Neighbors (KNN)
  - Input: current link quality measurements (RSS + SNR), reliability requirement, and initial data set
  - Output: selected SF

- SF selection process
  1) *Search* for *k* data points in initial data set
     - Most similar to current link quality measurements
  2) *Predict* the success / failure of packet reception under each SF
     - Based on the voting among the *k* data points
  3) *Select* the smallest SF predicted to provide a successful delivery
     - To maximize the throughput

# Runtime SF Control Solution



- Voting threshold of KNN algorithm
  - Required ratio of data points that vote positive when predicting a successful packet delivery
  - A higher threshold increases the link reliability

- Adjusting the voting threshold at runtime
  - Goal: meeting the link reliability requirement
  - Threshold adjusted (+/-) at runtime for each SF individually
  - Adjustments triggered when
    - New link reliability measurement is available
    - Link reliability requirement is changed

# Software Architecture

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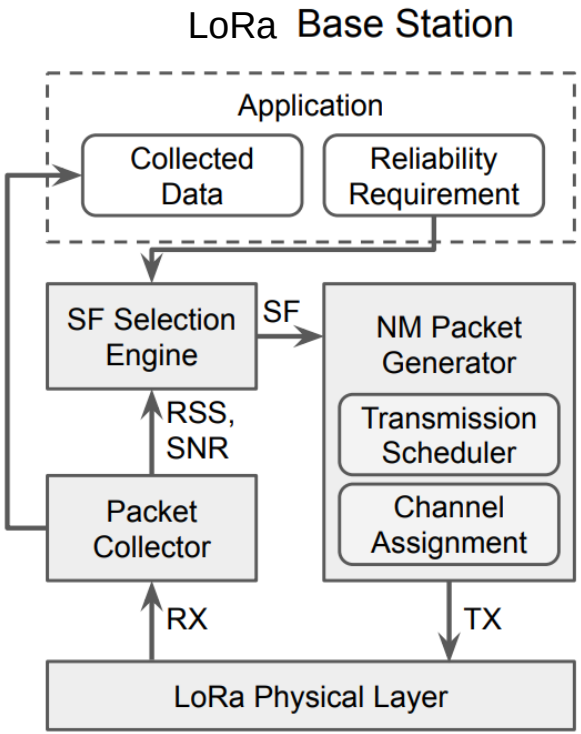
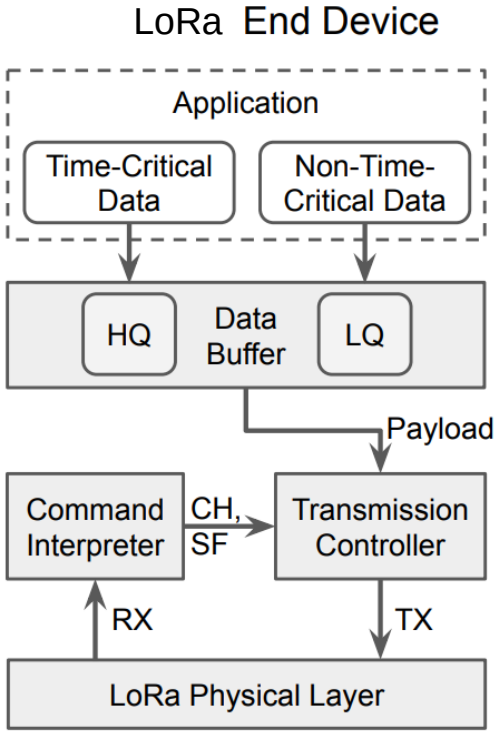
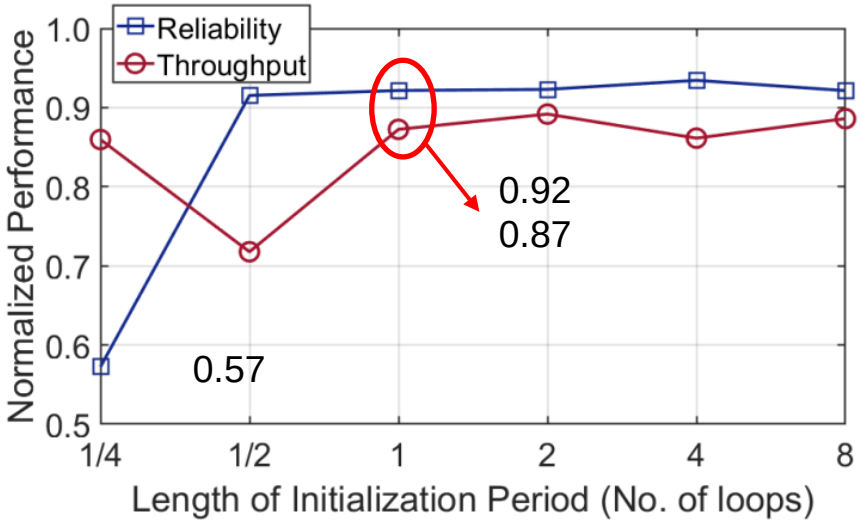


# Evaluation



- Impact of initialization period length
  - Performance when using the initial data set with different sizes (normalized to optimal)

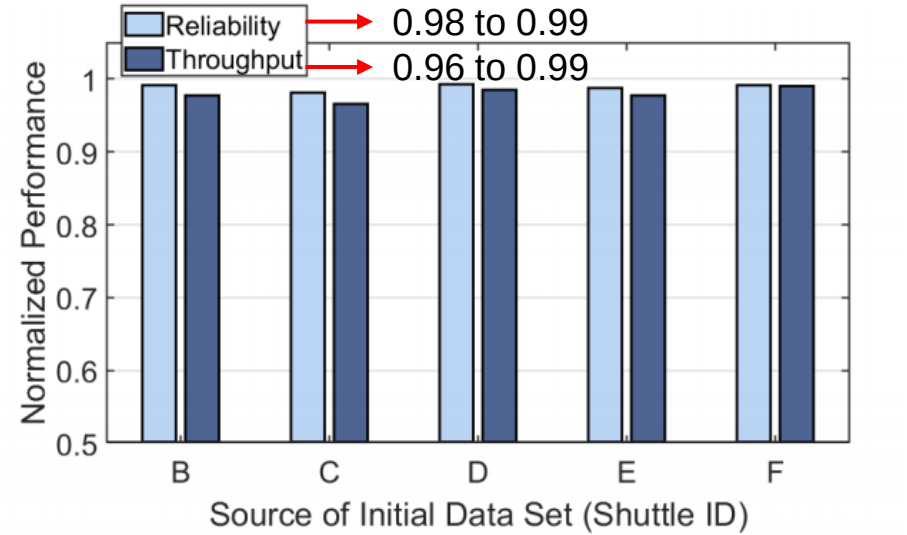



***Collecting one loop of initial data is enough to provide good SF selections***

# Evaluation



- Sharing the initial data among different shuttles
  - Use the initial data set collected from Shuttles B,C,D,E,F on Shuttle A
  - Performance normalized to using initial data on the same shuttle




***It is feasible to share the Initial Data Set among different shuttles***

# Evaluation

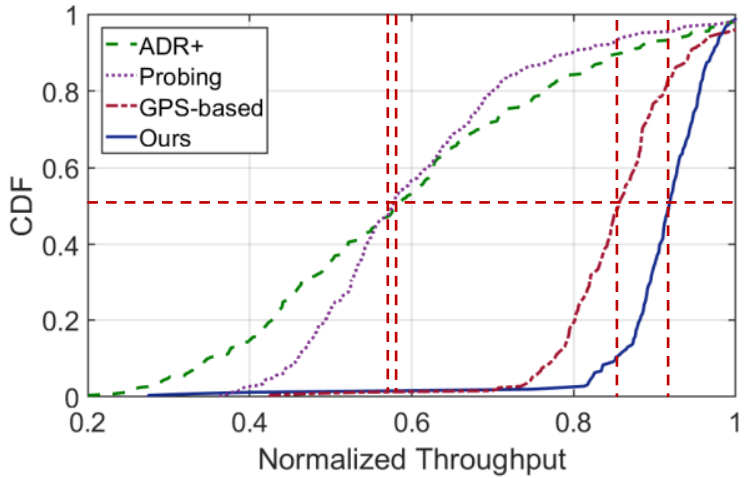


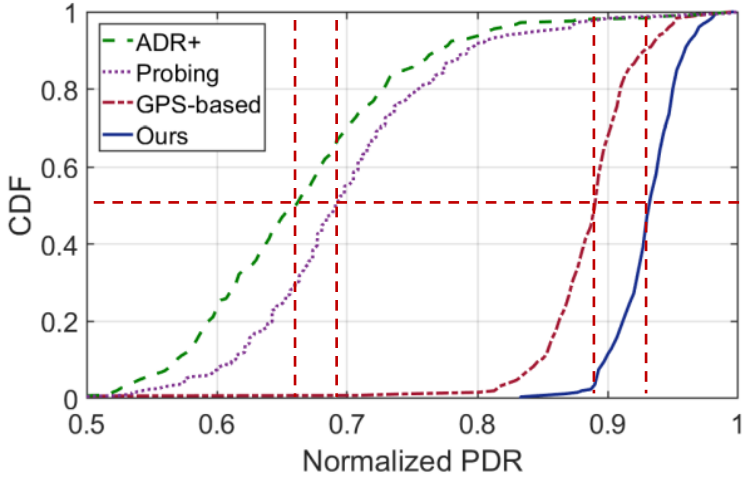
- Effectiveness of our runtime SF control solution
  - Performance measured from a shuttle for more than 100 hours
  - Compared against three SF selection baselines
    - ADR+: based on measured SNR
    - Probing: based on measured link PRR
    - GPS-based: based on GPS coordinates

# Evaluation



- Effectiveness of our runtime SF control solution
  - Median throughput: 0.92 (compared with 0.58, 0.57, 0.86)
  - Median PDR: 0.93 (compared with 0.66, 0.69, 0.89)




***Our solution provides the highest throughput and reliability***

# Conclusion

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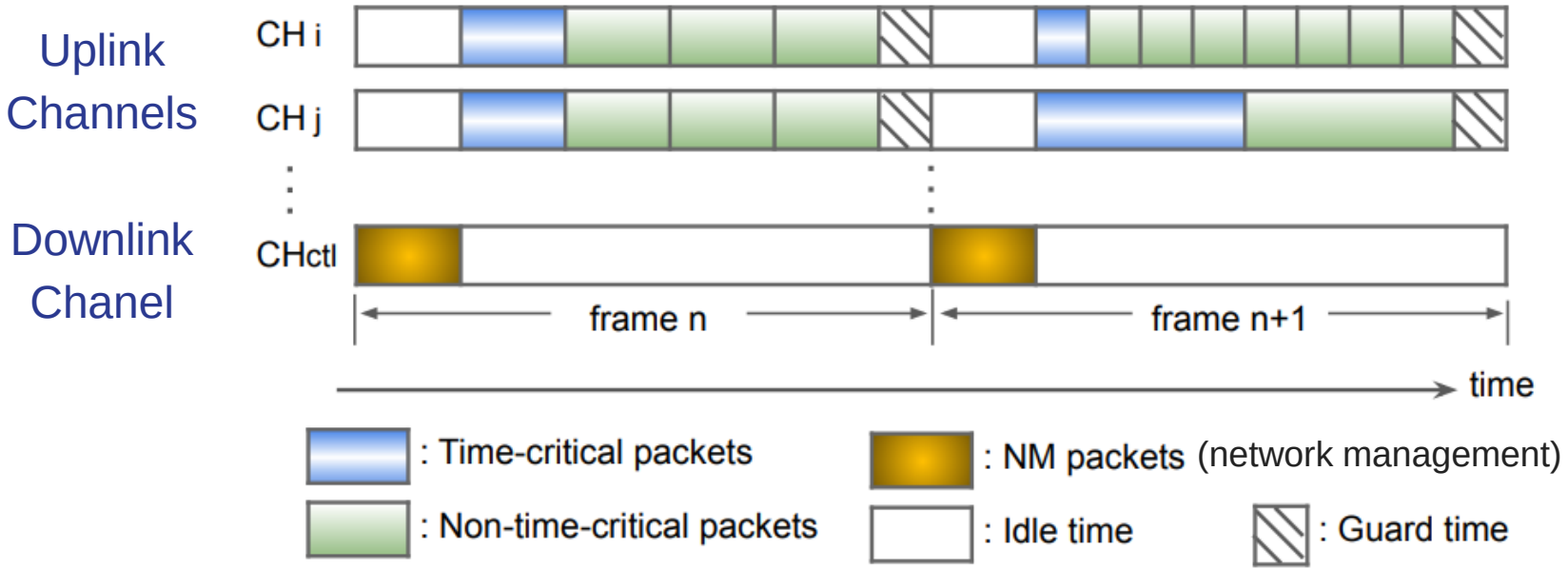
- We present a system that consists of low-cost COTS devices and collects data from six shuttles that circle our university campus using LoRa links
- Our empirical study shows the tradeoff between reliability and throughput when selecting SF for mobile LoRa end devices and the ineffectiveness of the existing SF selection methods
- We introduce a lightweight KNN-based solution that selects SF at runtime to meet the reliability requirement specified by the application and maximize link throughput

# Thanks for your attention!
# Questions?

# Backup Slides

# Time Frame and Channel

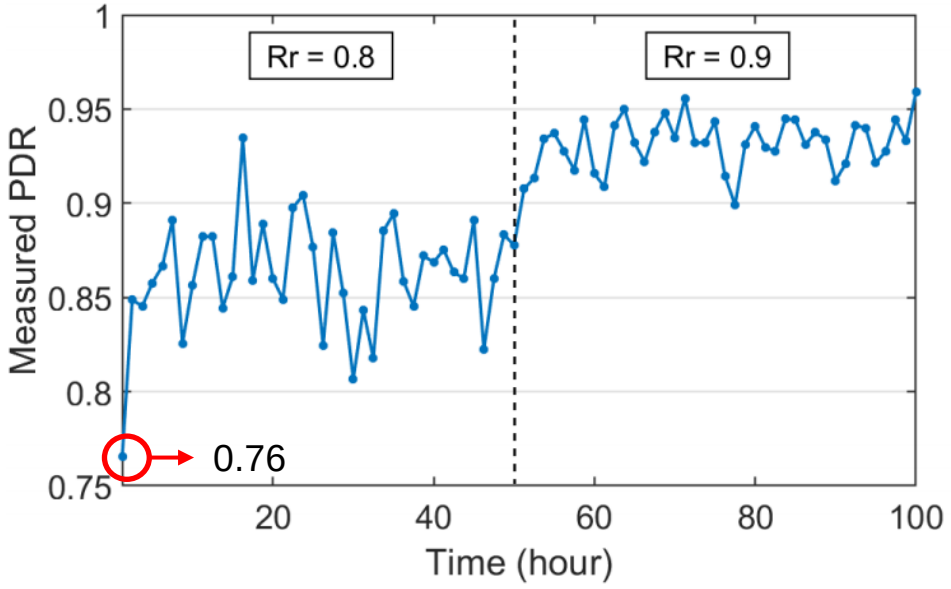




# Evaluation



- Performance under different link reliability requirements
  - An example data trace that shows the link reliability changes when the reliability requirement changes




***Meeting different reliability requirements***

# Evaluation

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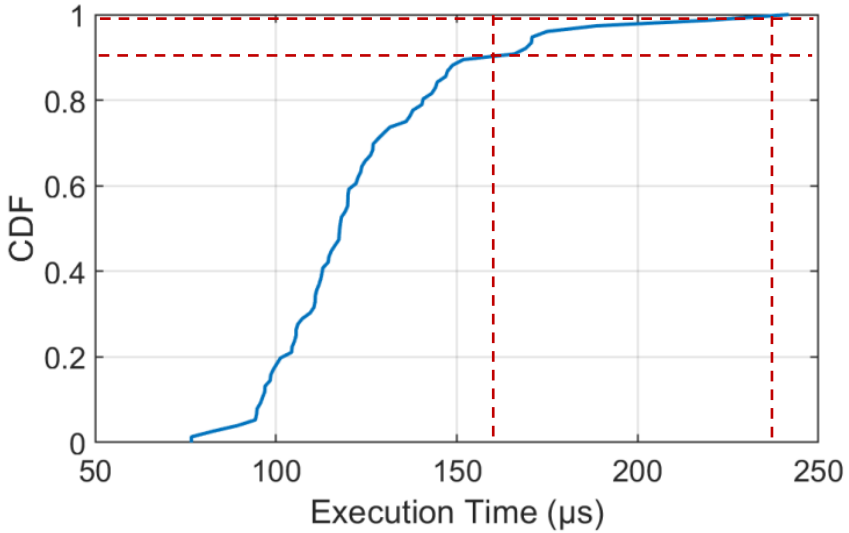
- Time efficiency of our runtime SF control solution
  - *The execution time measured on a Raspberry Pi computer*




***99% of the SF selections finish within 241 μs***