CurveALOHA:
Non-linear Chirps Enabled High Throughput Random Channel Access for LoRa

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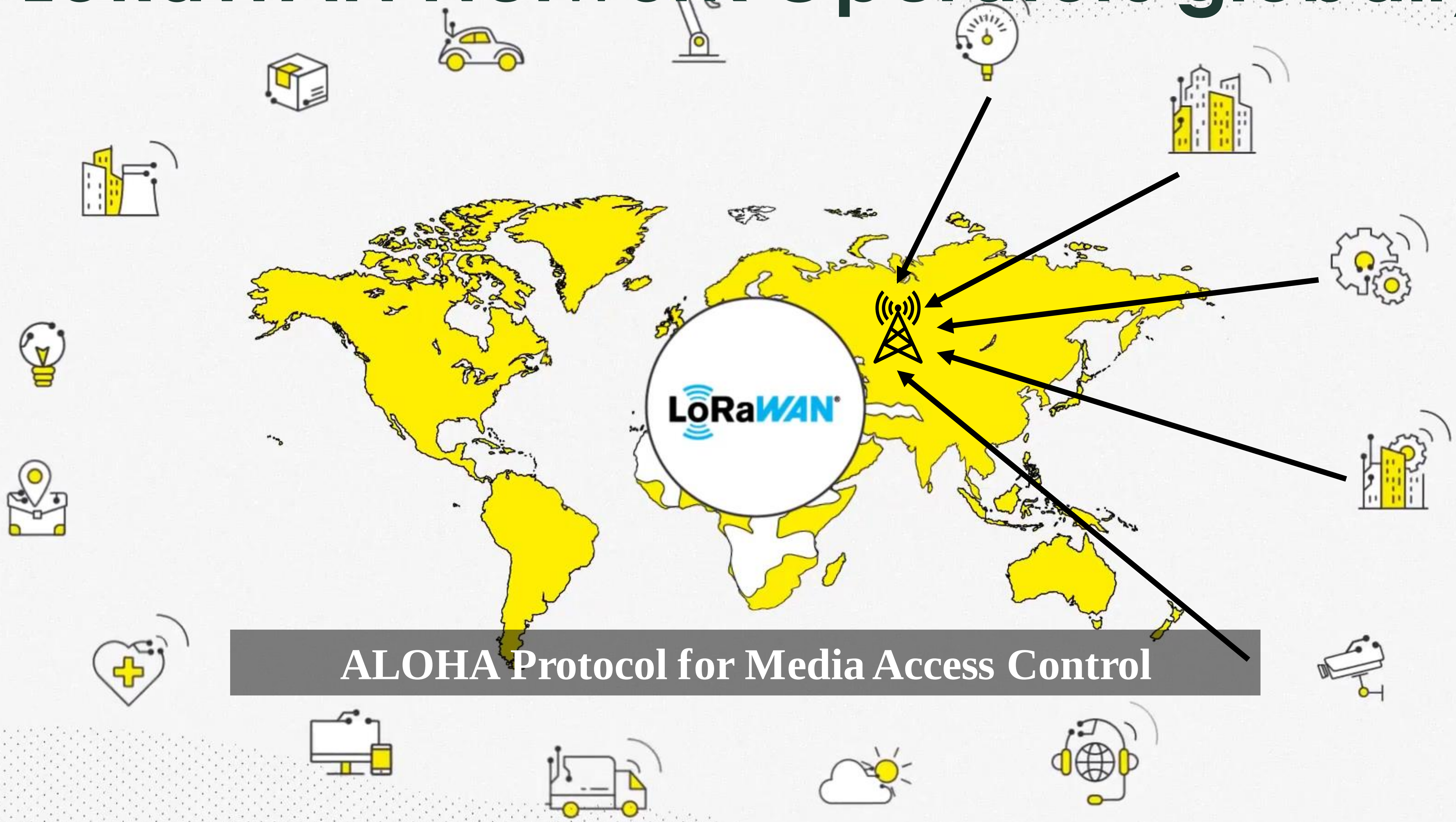
Smart World with Wireless Connection

Credits to LoRa Alliance https://lora-alliance.org/lorawan-coverage/

LoRaWAN Network Operators globally

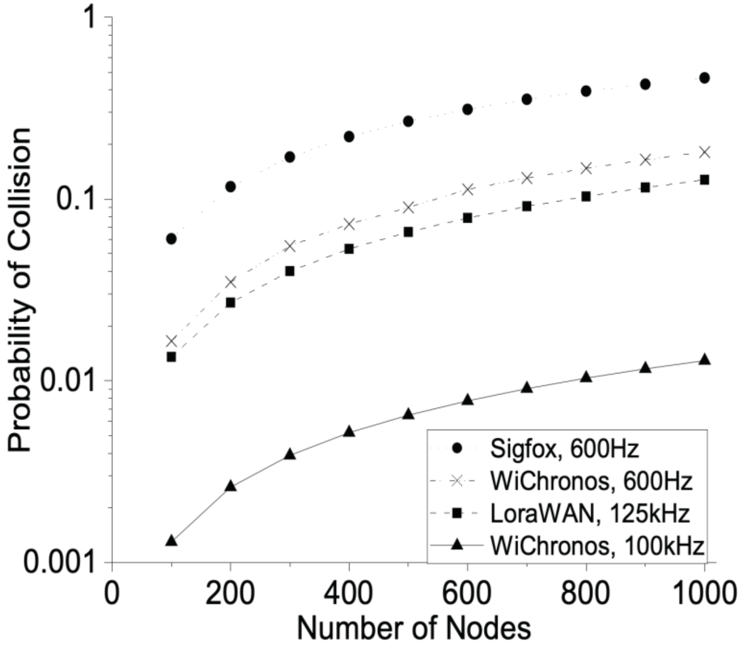


ALOHA Protocol for Media Access Control

Credits to LoRa Alliance https://lora-alliance.org/lorawan-coverage/

ALOHA Collision Probability

- **Profile the probability of collision for a given node transmitting a 1-byte message every ten minutes as a function of the network size**
    - A spreading factor (SF) of 7, code rate 4/5 and 125kHz bandwidth (BW)



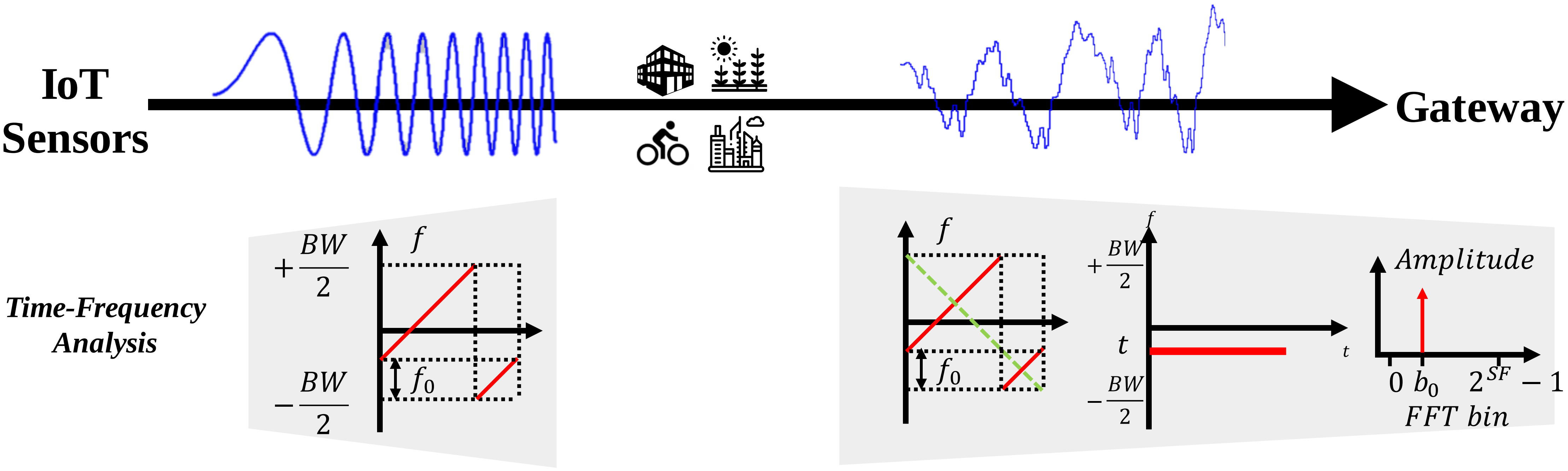
Up to 10% probability of collision with 1000 LoRa nodes

Credits to WiChronos MobiCom'20

Background on LoRa PHY Layer

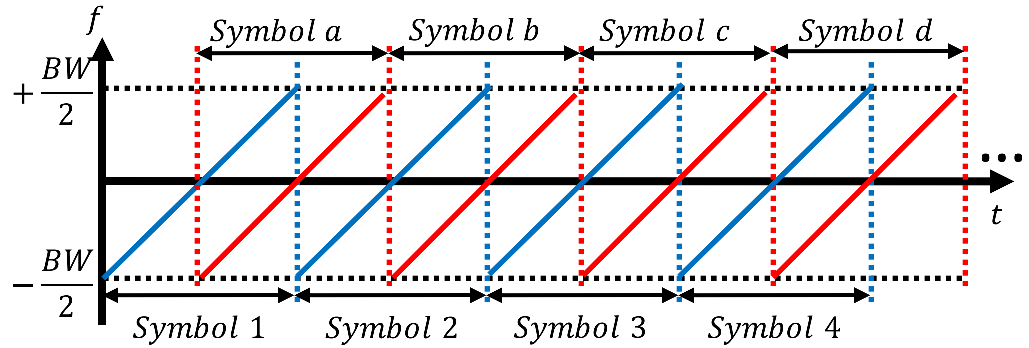
PHY Layer: Chirp Spread Spectrum Modulation

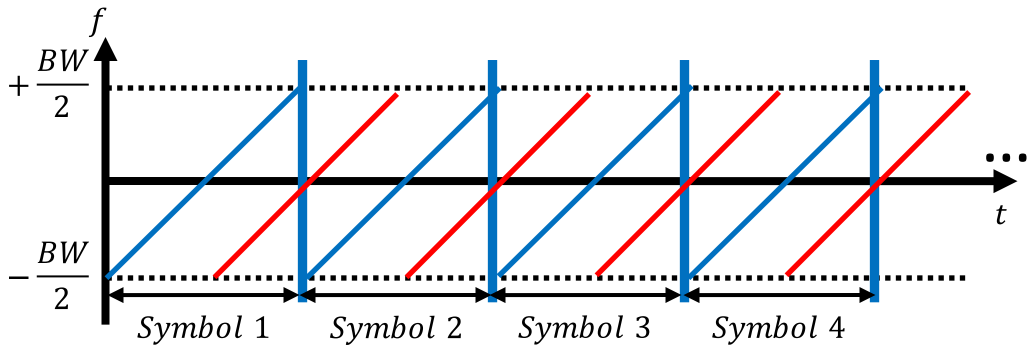
- **Bandwidth (BW):** *Fixed-bandwidth Channel, 125, 250, 500 KHz.*
- **Spreading Factor (SF):** *the amount of spreading code applied to the original data signal, from SF7 to SF12.*



Collision with ALOHA

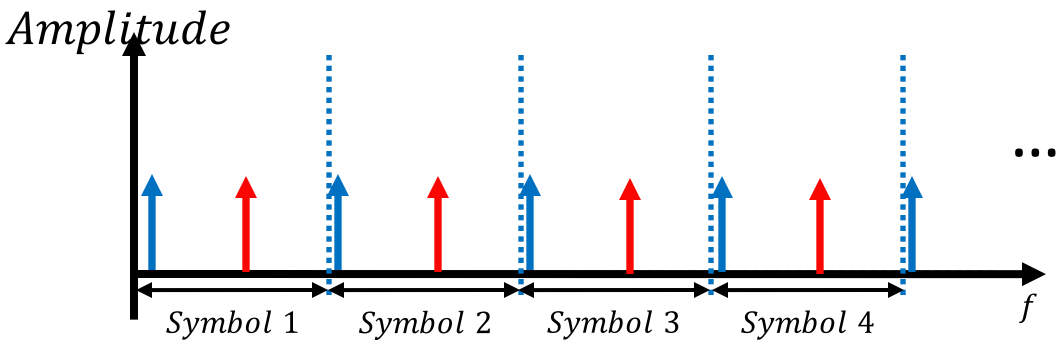
The weak signals are easily overwhelmed by the strong one.





Symbol Error Rate (SER)

- Expected: [0,0,0,0]
- Actual: $[0, b_0, 0, b_0]$ (depends on the peak)



Existing LoRa MAC Design

Low-cost and accurate carrier-sense methods

LMAC
MobiCom ’20

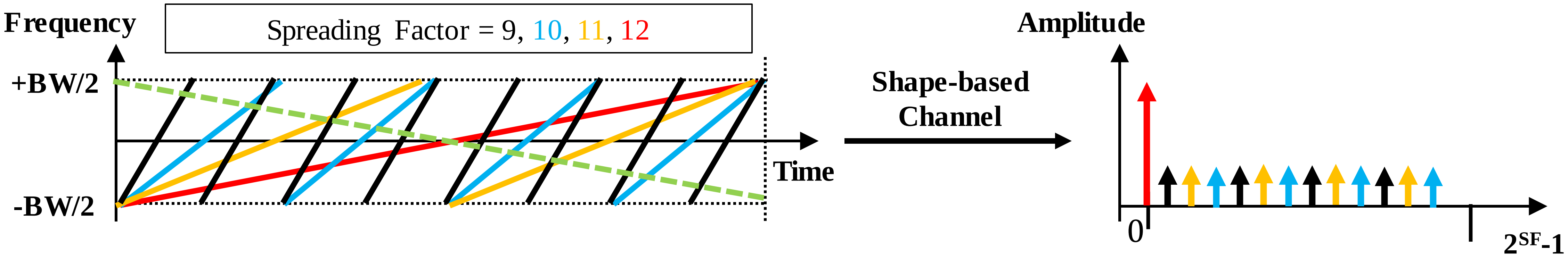
DeepSense
arXiv’19

p-CARMA
EWSN ’20

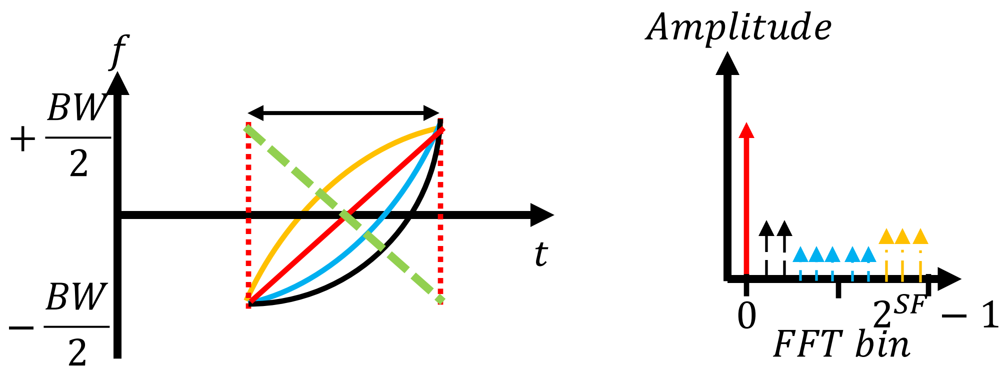
Extra Complexity and Cost

Key Idea of CurveALOHA

- **Starting from the SF-enabled Logical Channel**

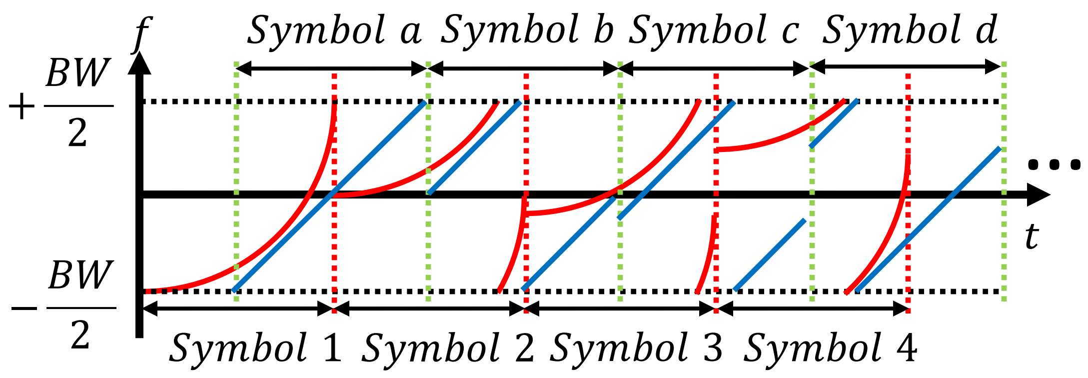


- **CurveALOHA: Shape-based Logical Channel with the same SF**



Key Idea of CurveALOHA

- **Different Shapes of Chirps are orthogonal to each other as the Logical Channel for Concurrent Transmission without Collision**



- Noise Resilience of Non-linear Chirps
- Collision between different Chirps
- MAC-Layer Design for Chirp Selection
- Implementation & Evaluation

Noise Resilience of Non-linear Chirps

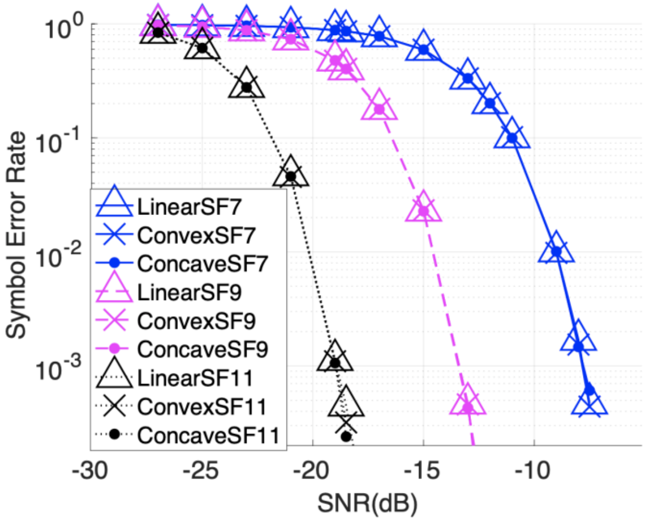
- **Non-linear Chirps can also focus the spectral energy to suppress noise**

1. Initial frequency offset for Modulation.

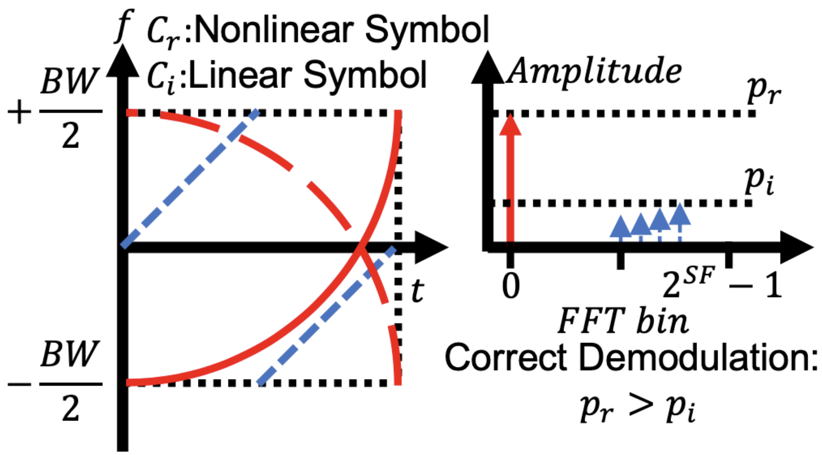
2. Dechirp for Demodulation.

- Convex up-chirp
  $f(x) = x^2$

- Concave up-chirp
  $f(x) = 2x - x^2$



Collision between Different Chirps



Key Observation:

Dechirp with a mismatched base down-chirp will scatter the energy to different frequency. Thus, different chirps provide the opportunity for concurrent transmission.

MAC-Layer Design for Selection

(1): $quadratic1 — f(t) = t^2$
(3): $quartic1 — f(t) = t^4$

(2): $quadratic2 — f(t) = -t^2 + 2t$
(4): $quartic2 — f(t) = -t^4 + 4t^3 - 6t^2 + 4t$

- Given a Pool of Non-linear and Linear Chirps, we compute the *SIR threshold* for each collision scenarios with a pair of Chirp Types

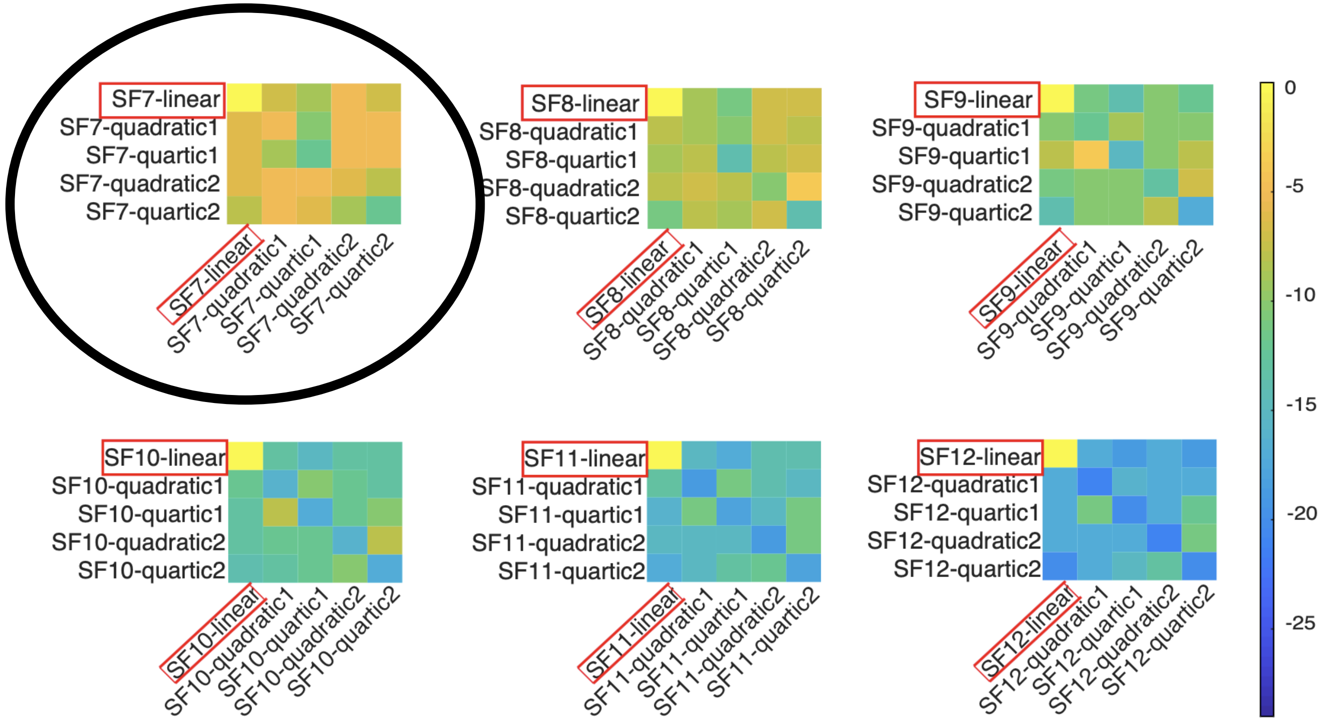


Fig. 5. SIR threshold heatmap of 5 chirps with the same SF. Each block indicates the SIR threshold of a reference signal (i.e., row mark) under an interference signal (i.e., column mark). The rectangle denotes the LoRa linear chirps. With a darker color, the block corresponds to a lower SIR threshold.

MAC-Layer Design for Selection

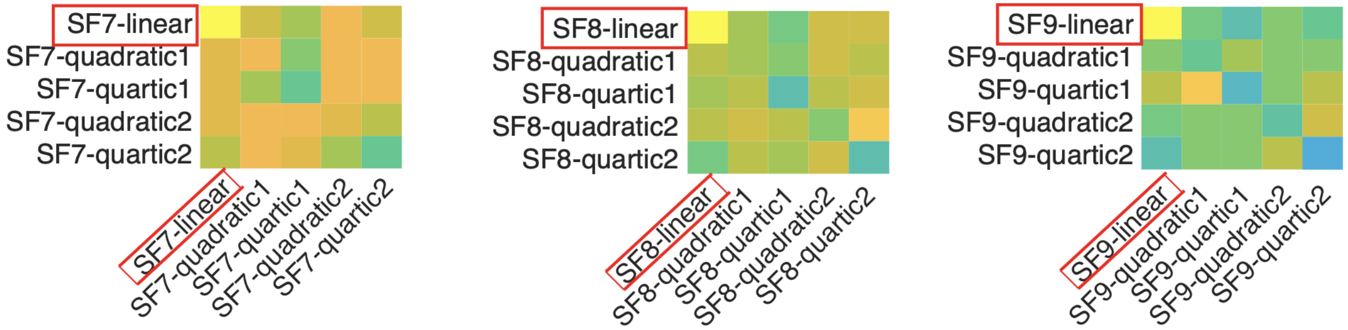
(1): $quadratic1$—$f(t) = t^2$	(2): $quadratic2$—$f(t) = -t^2 + 2t$
(3): $quartic1$—$f(t) = t^4$	(4): $quartic2$—$f(t) = -t^4 + 4t^3 - 6t^2 + 4t$

- Problem Formulation:

Given n available logical channels (i.e., $\{C_1, C_2, ..., C_n\}$) when an end node has a packet to transmit at time t, it selects one logical channel $C(t)$ to transmit the packet immediately.

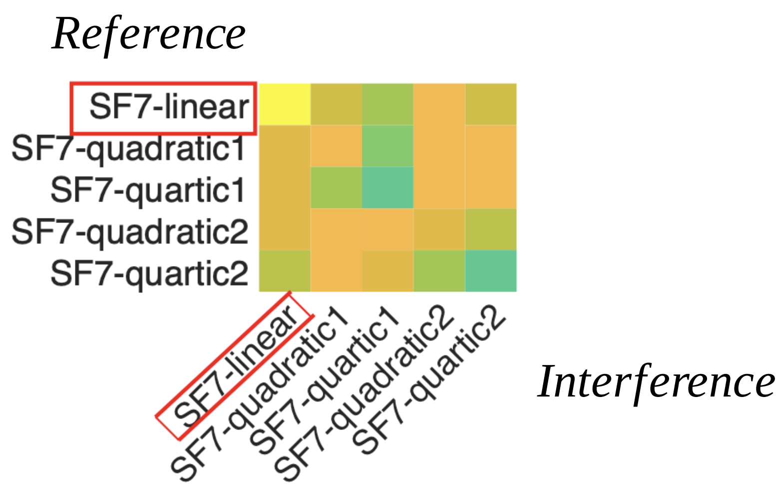
- Stateless *CurveALOHA-1*: No prior knowledge but randomly select $C(t)$

- Stateful *CurveALOHA-2*: Weight-based Selection of $C(t)$ from Prior Transmissions and Existing SIR Threshold Map



Stateful CurveALOHA-2

- Stateful *CurveALOHA-2*: Weight-based Selection of *C(t)* from {C1 , C2 , ..., Cn })
  - Prior Transmissions and
  - Existing SIR Threshold Map



- Initialization: $p_k = \frac{w_k}{\sum_{j=1}^{n} w_j}$

- Adapt the Weight with the received PDR

$$w_k(m) = w_k(m) \times \boxed{\tau^{1-P_k(m)/P_{thres}}}$$

- Adapt the weight with the SIR Threshold Map

$$w_j(m+1) = w_j(m) \times \delta_j(C_k), for\ j = 1, \ldots, n$$

- As a result, we can use local observed network status to optimize channel selection

Implementation

Metric:
- Symbol Error Rate (SER)
- Packet Delivery Rate (PDR)
- Throughput (Symbols/Second)

Baseline:
- Standard LoRaWAN with ALOHA
- LMAC MobiCom '20 (with Reported Statistics)

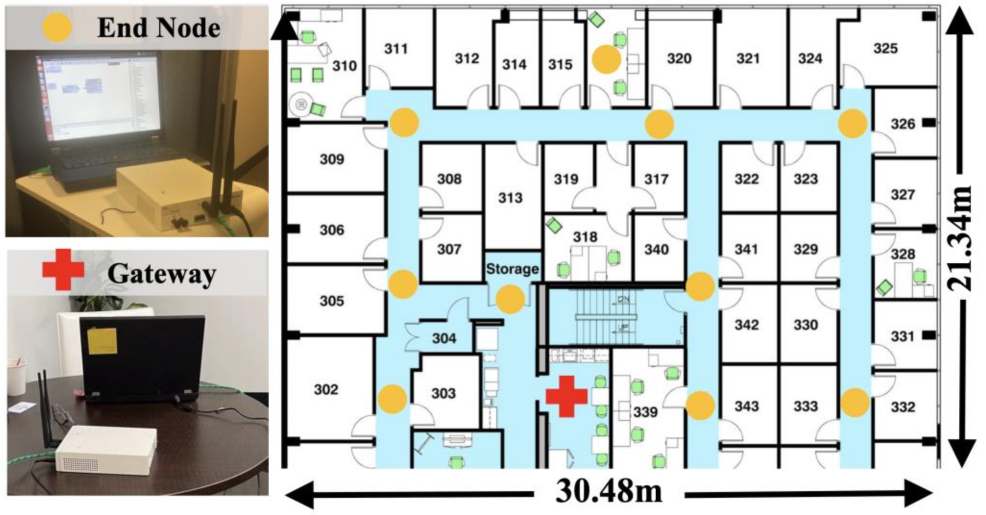
Non-linear Chirp Pool with the Linear One:

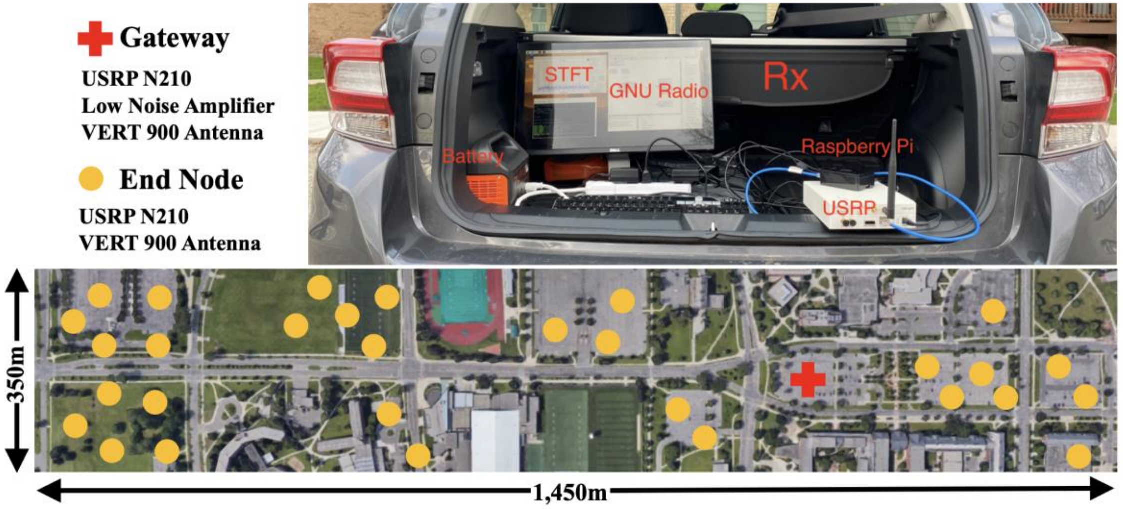
(1): $quadratic1$—$f(t) = t^2$

(3): $quartic1$—$f(t) = t^4$

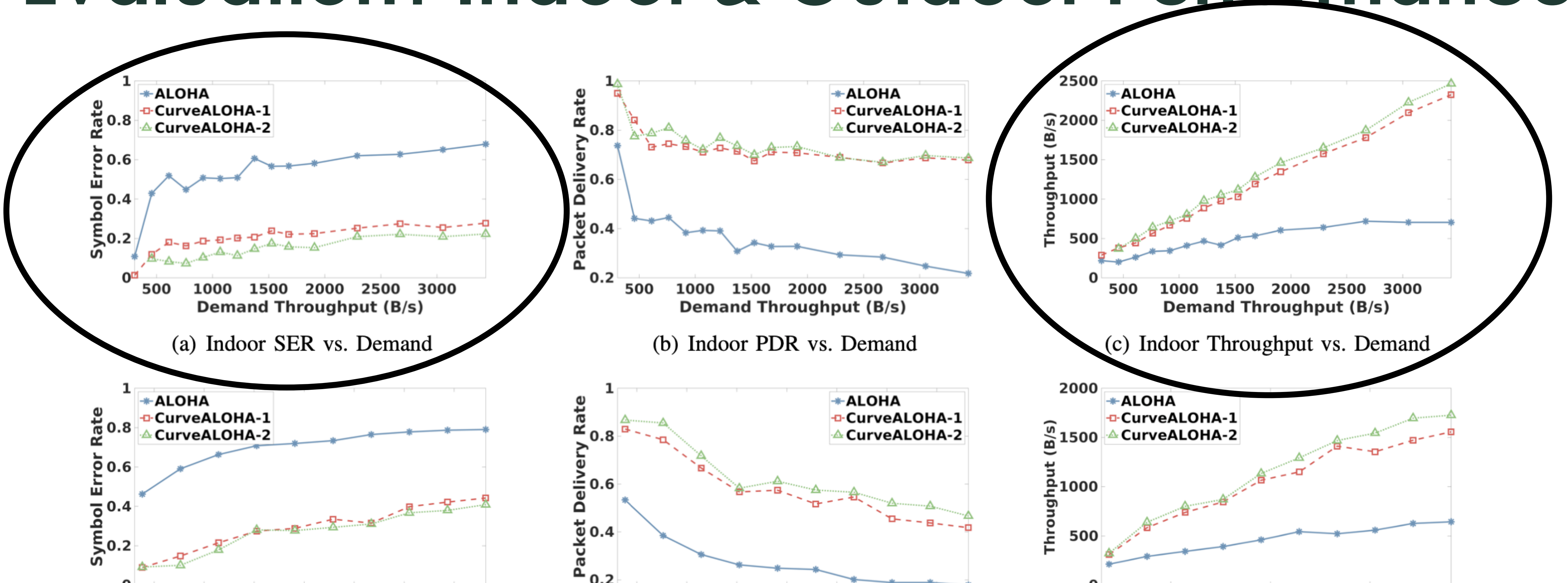
(2): $quadratic2$—$f(t) = -t^2 + 2t$

(4): $quartic2$—$f(t) = -t^4 + 4t^3 - 6t^2 + 4t$





Evaluation: Indoor & Outdoor Performance



(a) Indoor SER vs. Demand (b) Indoor PDR vs. Demand (c) Indoor Throughput vs. Demand
(d) Outdoor SER vs. Demand (e) Outdoor PDR vs. Demand (f) Outdoor Throughput vs. Demand

Fig. 8. Network performance comparison among ALOHA and CurveALOHA on SER, PDR, and throughput for indoor (top) and outdoor (bottom) experiments.

Evaluation: SOTA and Fairness

TABLE I
COMPARISON OF THROUGHPUT GAINS AGAINST ALOHA

Demand (B/s)	1,000	1,500	2,000	2,500	3,000	3,500
LMAC-2[a]	2.22×	1.83×	1.70×	1.76×	1.81×	1.87×
CurveALOHA-2	2.33×	2.22×	2.38×	2.81×	2.76×	2.70×

[a]Results reported in Figure 13a of LMAC [11].

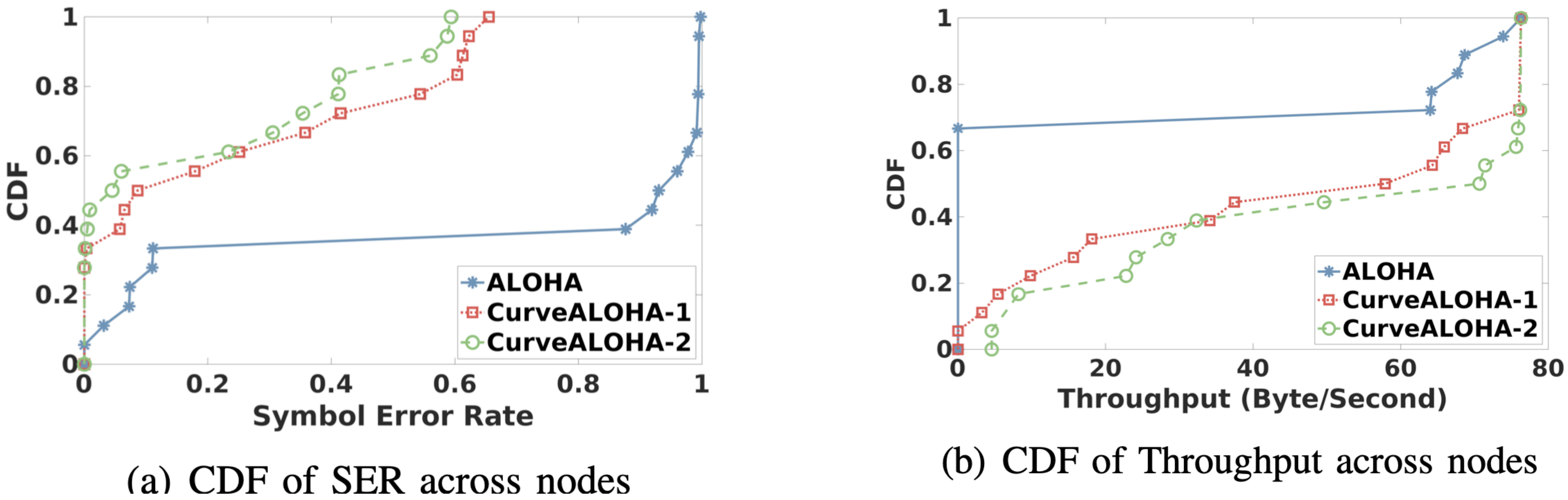
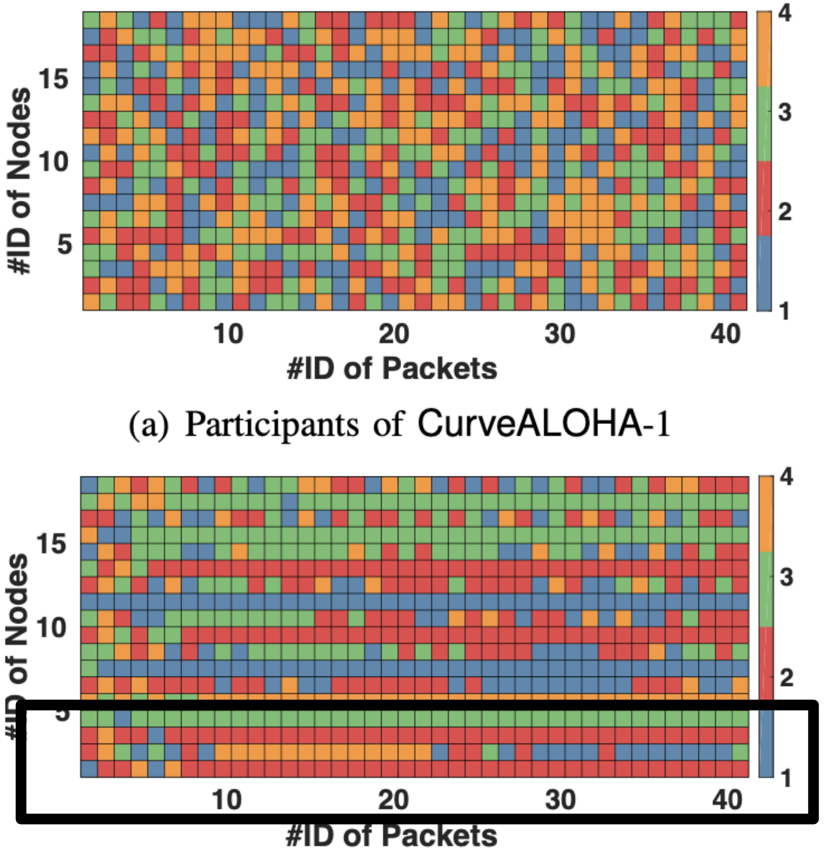


Fig. 9. CDFs of the per-node network performance (demand 1,400 B/s).

Evaluation: Indoor & Outdoor Performance

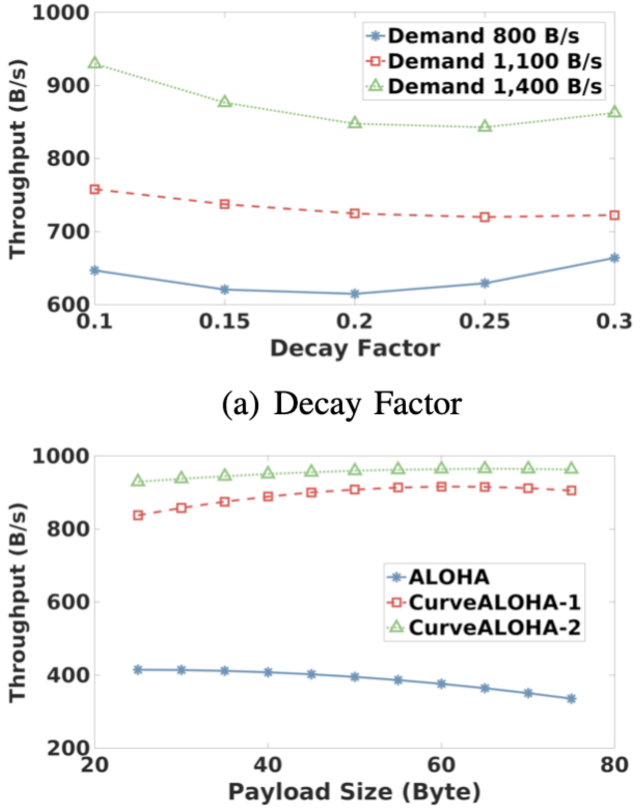


(a) Participants of CurveALOHA-1

(b) Participants of CurveALOHA-2

Fig. 11. Participant selection of non-linear chirps in various nodes and packets for CurveALOHA-1/2.

$$w_k(m) = w_k(m) \times \tau^{1-P_k(m)/P_{thres}}$$



(a) Decay Factor

(b) Payload Size

Fig. 12. Achieved throughput vs. various decay factors for CurveALOHA-2 and payload size with demand throughput of 1,400 B/s.

Conclusions & Future Work

METERING

AGRICULTURE

SMART CITIES

BUILDINGS & FACILITIES

INDUSTRY

- CurveALOHA Enables High Network Throughput Random Channel Access via Non-linear Chirps

- Future Work
  - Non-linear Chirp Selection
  - Extend the Orthogonal Coding Space with the SF and BW

HEALTHCARE & E-HEALTH

ENTERPRISE

TRANSPORTATION & FLEET MANAGEMENT

OPERATORS & TELECOMS

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