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Attack on Machine Learning based Physical Layer Key Generation scheme

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Overview

Working on project regarding Physical Layer Security

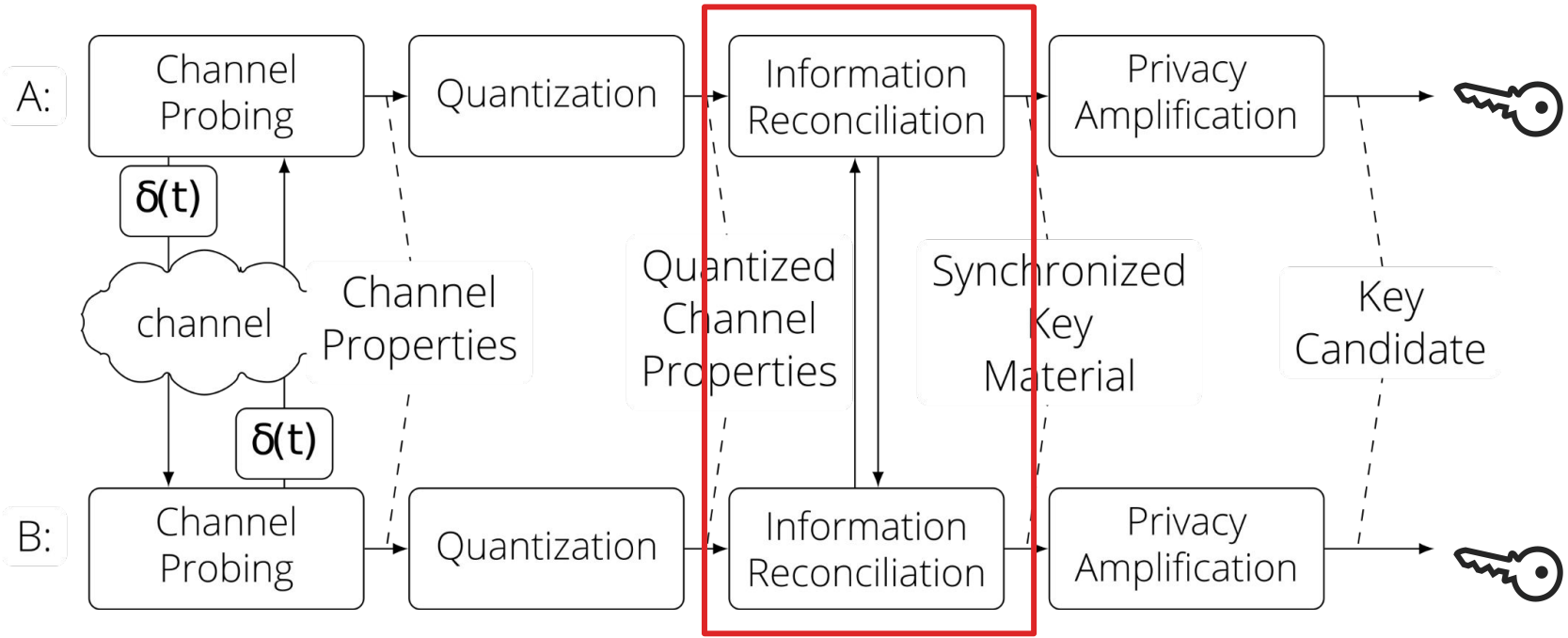
Tried using an existing, already published method:
P. Walther and T. Strufe, *Blind twins: Siamese networks for non-interactive information reconciliation* [0]

Discovery: Method **not working** as expected

Publish our findings (regarding existing method):
Re-Implementation, evaluation of results, code is public[1]

[1] https://dud-scm.inf.tu-dresden.de/dud/ml-based-physical-layer-key-generation

“Classical” Physical Layer Key Generation (PLKG)
Pipeline-Approach



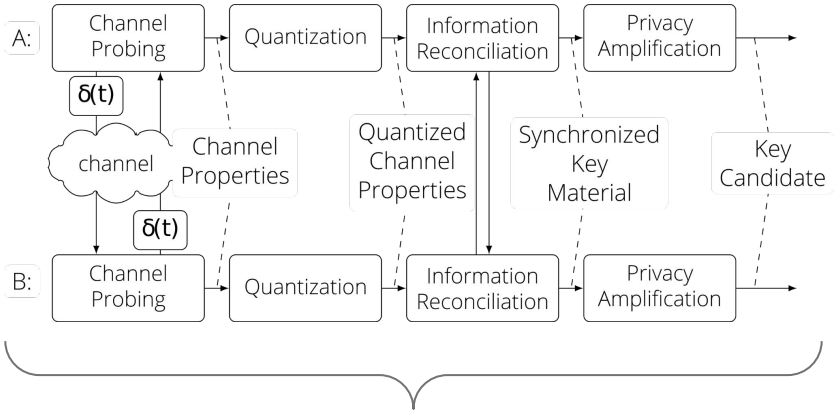
Original Idea
of the method by Walther et al. [0]

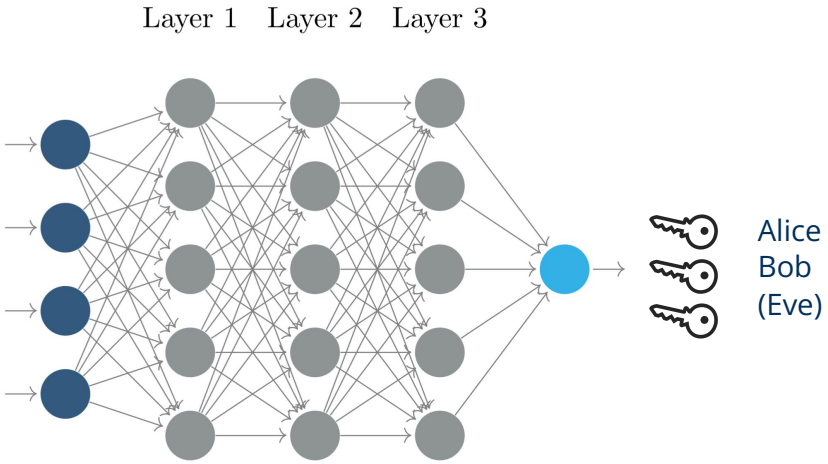
Solve Information Leakage problem:

→ use **one algorithm** for **all steps** of pipeline

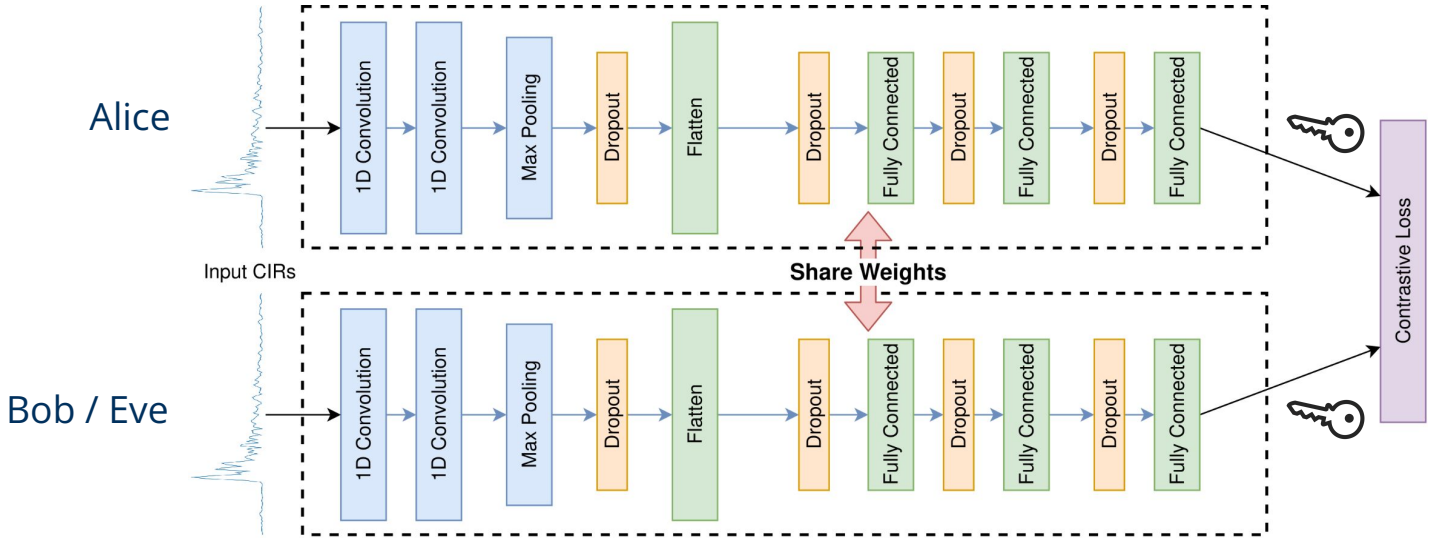
More specifically:
Neuronal Network with

- Input: Channel Impulse Response (CIR) of Alice, Bob, (Eve)
- Output: Keys for Alice, Bob, (Eve)

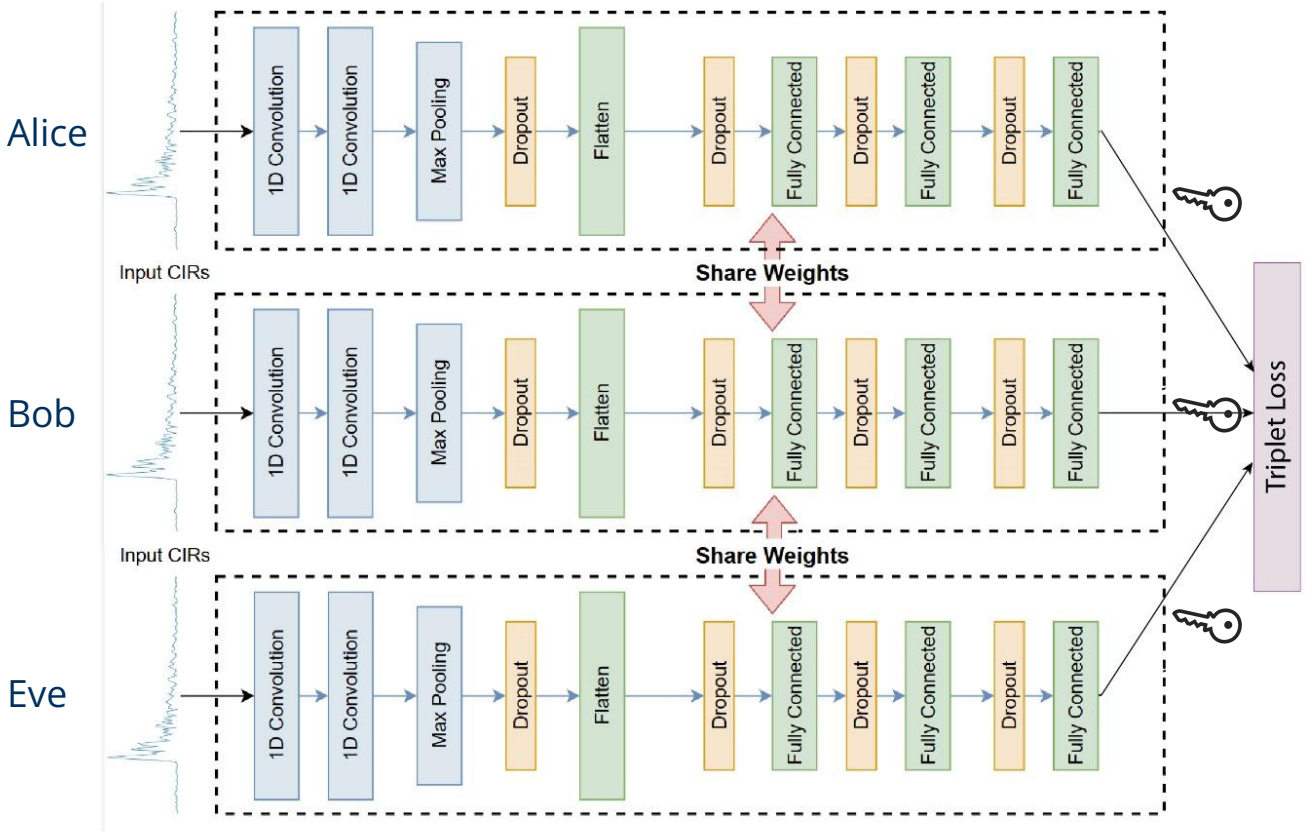




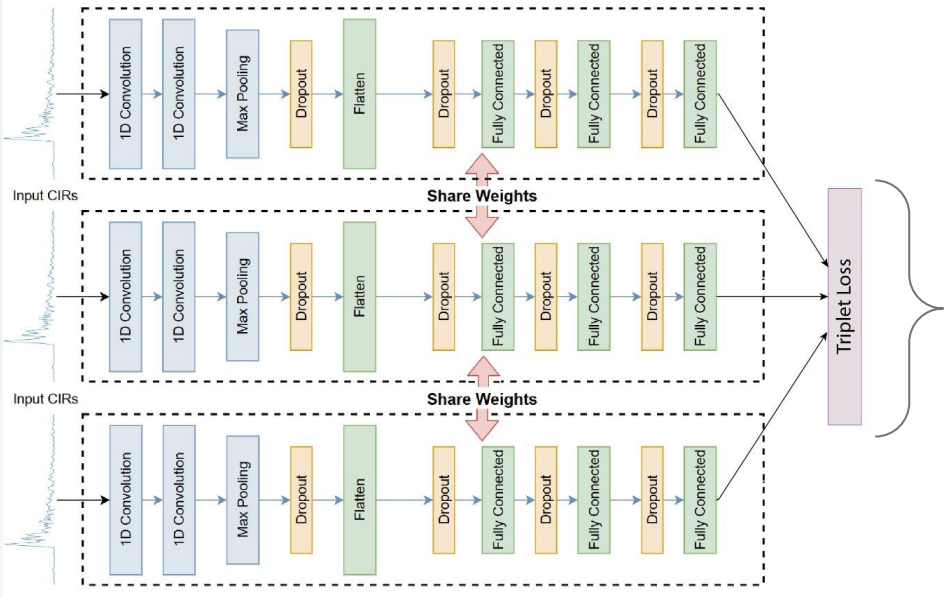
Network Architecture: Siamese Twin Network



Network Architecture: Triplet Network



Network Architecture: Triplet Network
Loss Function



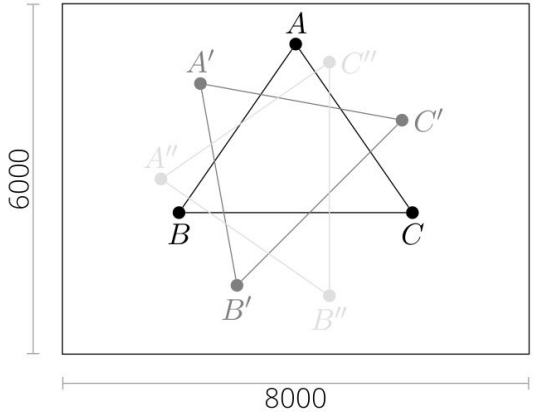
$$L(X_A, X_P, X_N) = \max(D_P - D_N + m, 0)$$

$$D(x, y) = y(1 - x) + (1 - y)x$$

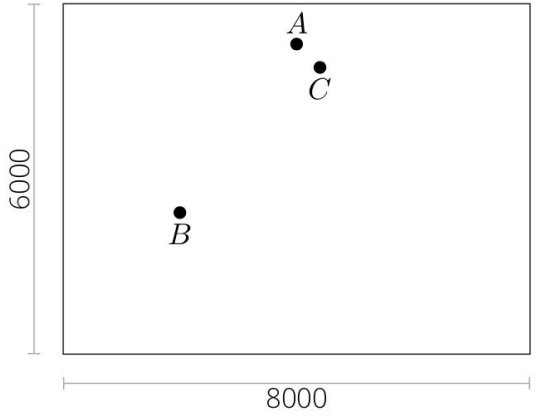
Dataset
used for training original method

Each communication partner:
Sending impulse, others measure signal (Channel Impulse Response)

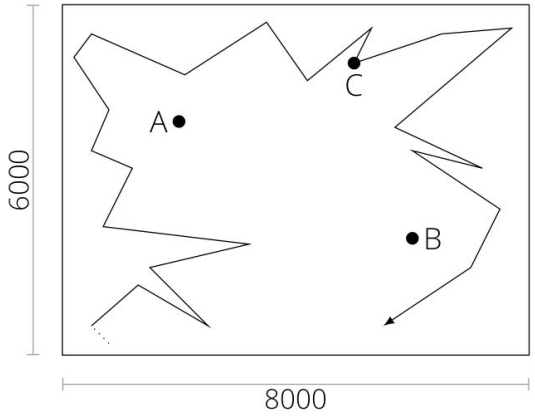
Each scenario:
Static or Dynamic
Same amount of measurements



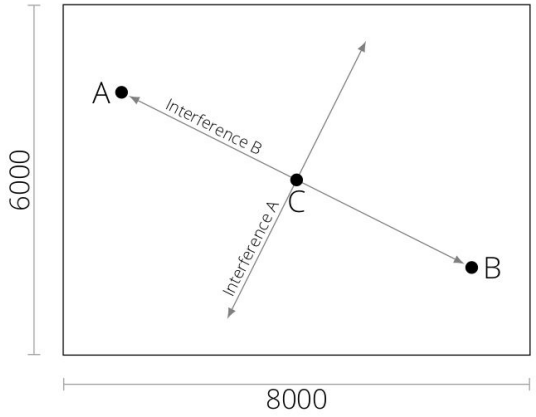
(a) Scenarios: Static A,B,C



(b) Scenario: Static D



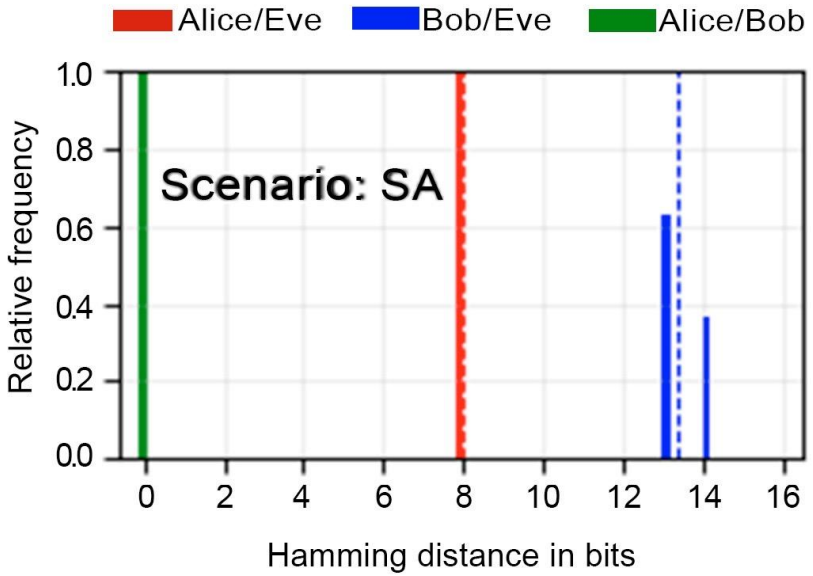
(c) Scenario: Moving Eve

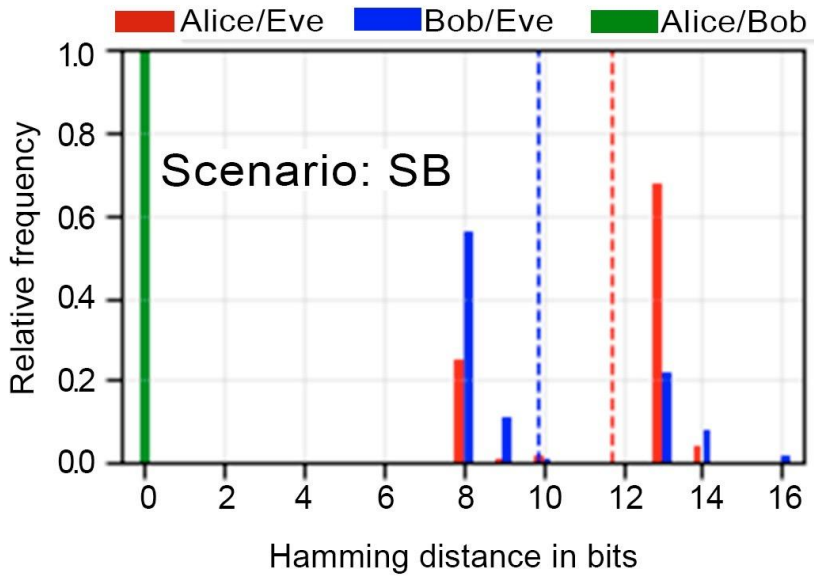


(d) Scenarios: Interference A,B

Original Results - Examples Static Scenarios

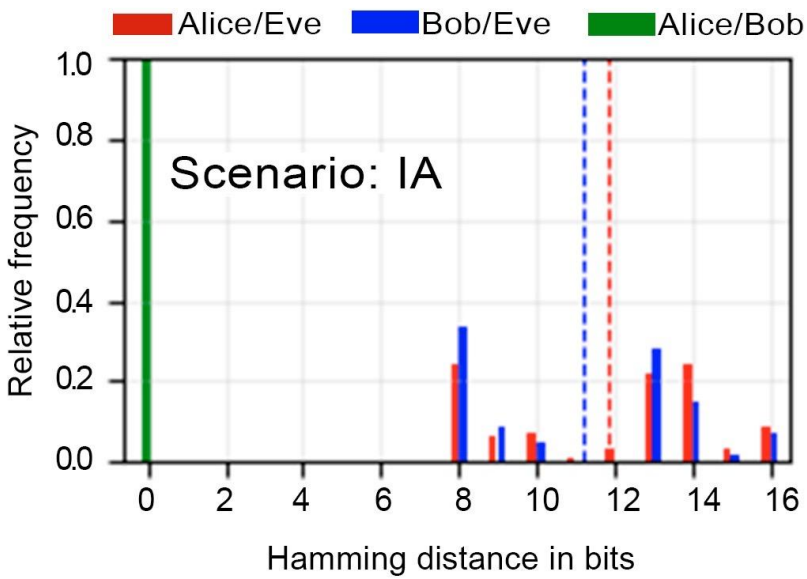
Walther et al. [0]

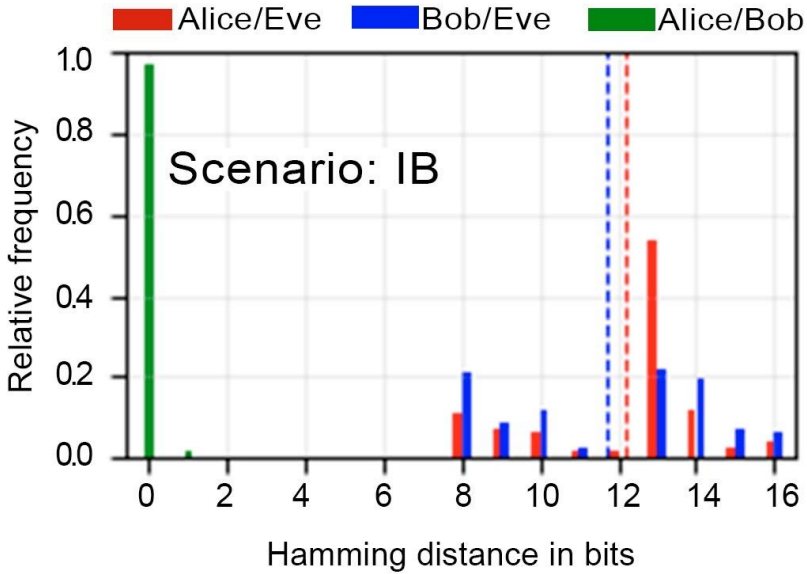




Original Results - Examples Dynamic Scenarios

Walther et al. [0]

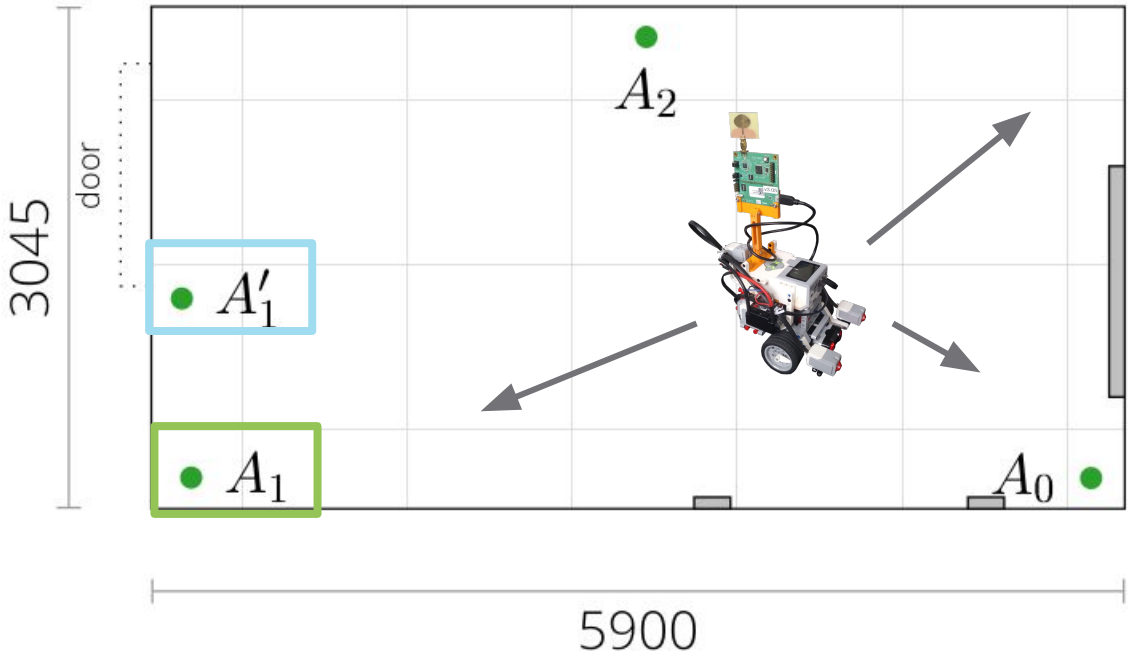




Dataset
used for training “our” model [2]

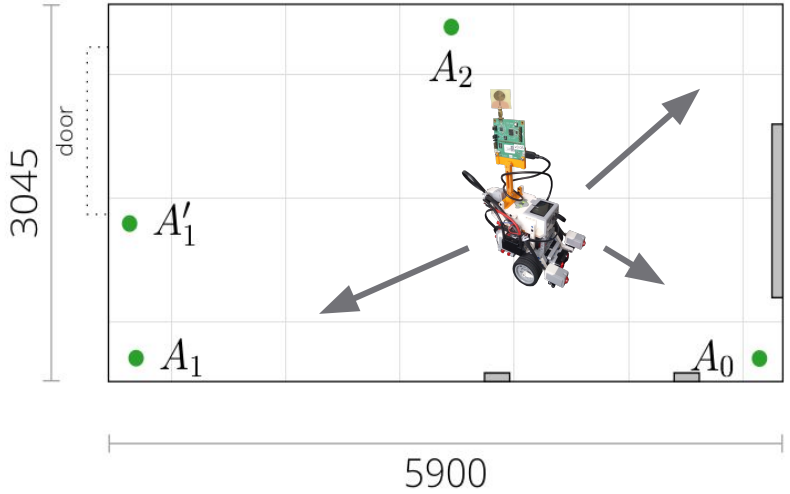
Asymmetric Setting

Symmetric Setting



Dataset
used for training “our” model

Static	Dynamic (+ Robot)
Symmetric-No-Move	Symmetric
Asymmetric-No-Move	Symmetric-Varying-Speed
	Asymmetric
	Asymmetric-Reflector

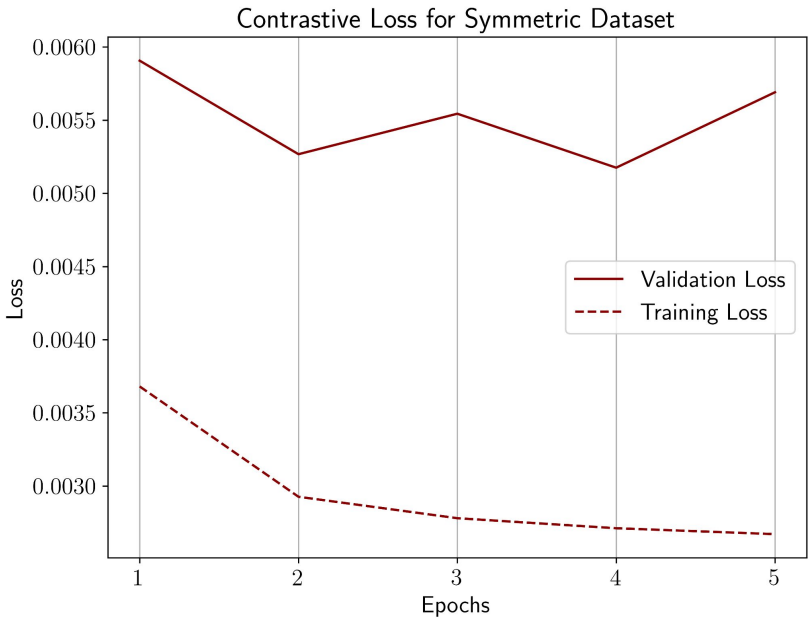


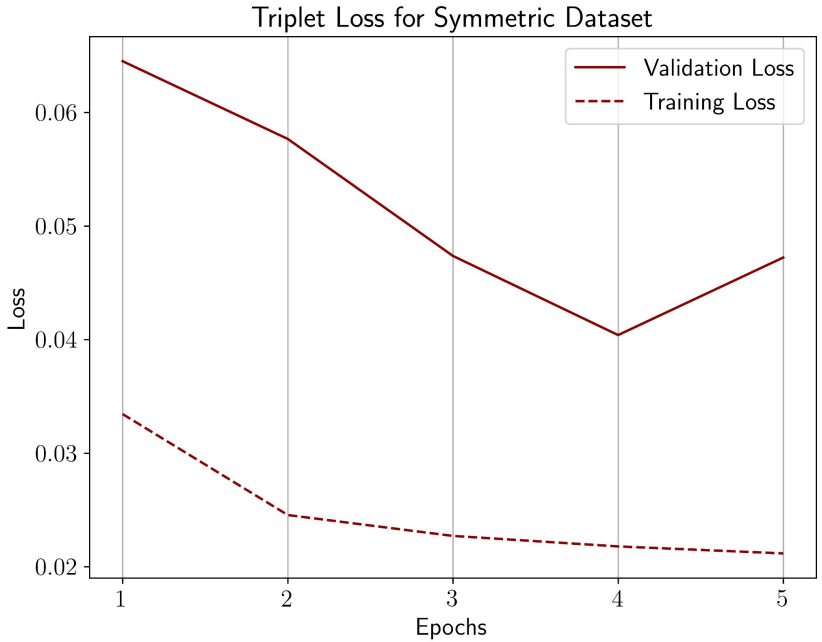
Dataset was evaluated for randomness

Dataset
used for training “our” model

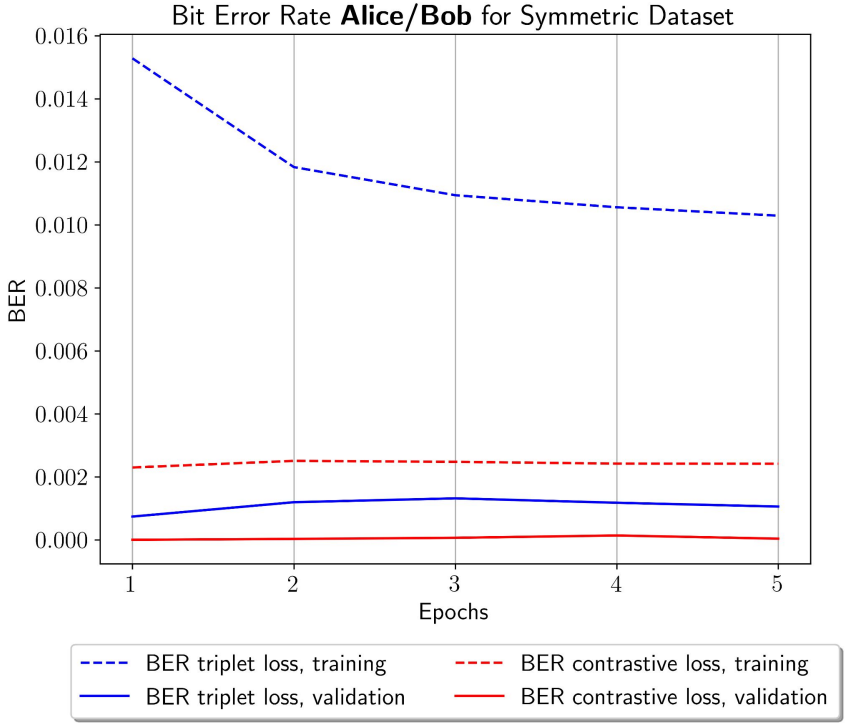
Data Set	Duration	Realizations
symmetric	56 h	845 250
asymmetric	19 h	281 595
reflector	20 h	299 730
var. speed	16 h	237 424
no movement	40 min	5418
total	111 h 40 min	1 669 417

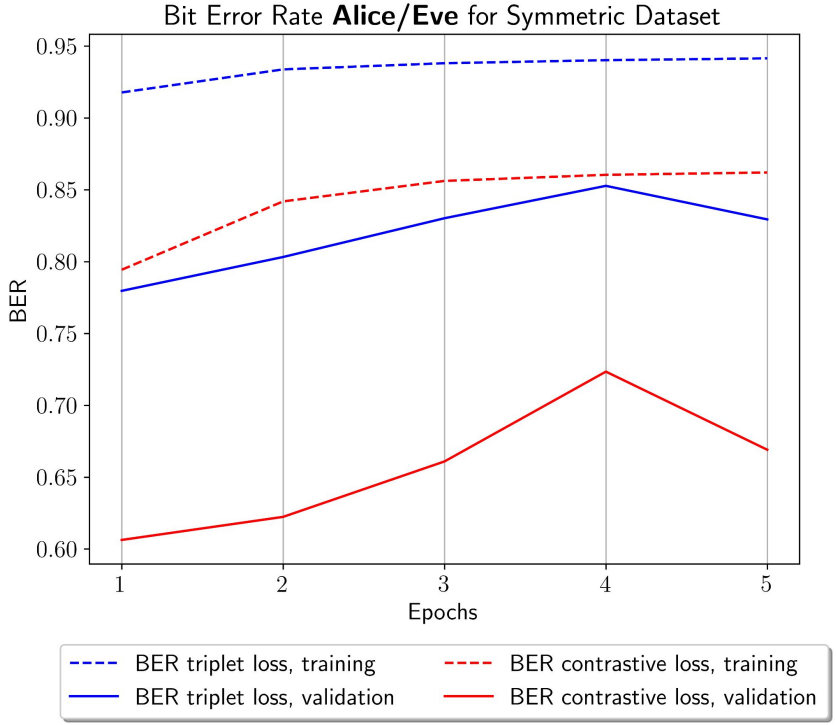
Results - Loss for Siamese + Triplet Network
for the symmetric dataset



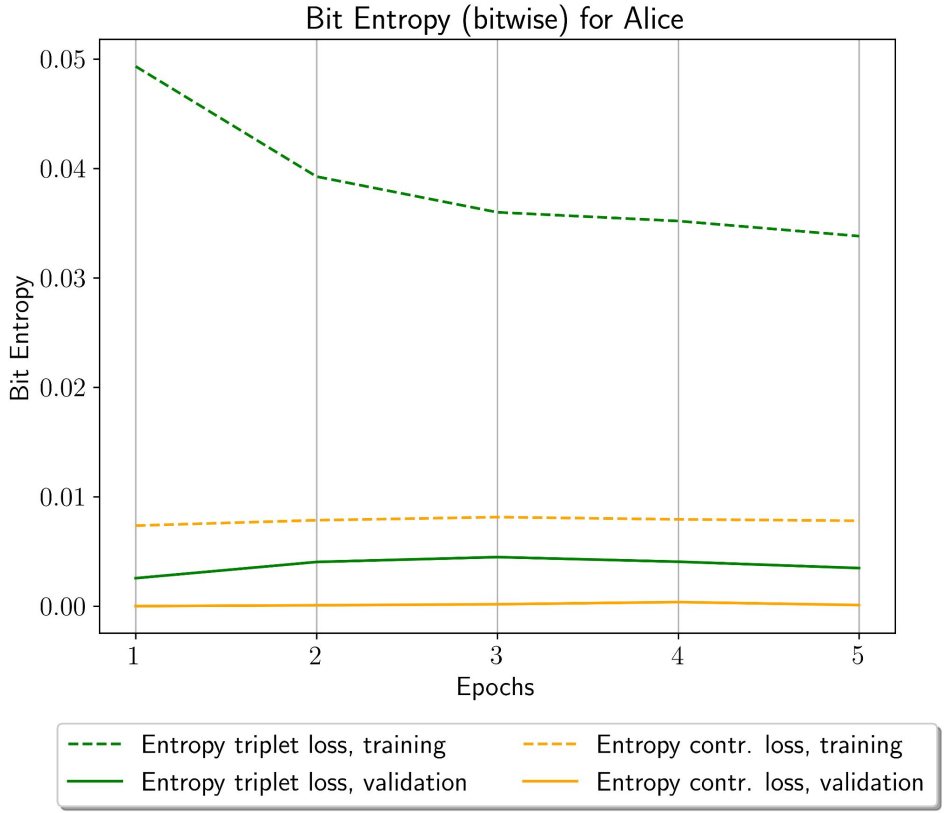


Results - Bit Error Rate (BER)
for **Alice/Bob** and **Alice/Eve** respectively





Results - Bit Entropy (for Alice)



Key Analysis
for the **static** scenarios, **Triplet-Network**

Predicted keys / participant: 1600

Scenario		Most common key(s) (out of 1600 predicted)	#unique keys	Notes
Symmetric-No-Move	**Alice/Bob**	`0011010100100110` (1384x)	12	
	Eve	`1100101111011000` (1278x)	21	Inverse key of Alice/Bob (except for 2 identical bits)
Asymmetric-No-Move	**Alice/Bob**	`0010111110011100` (1473x) `1101000100100011` (120x)	9	Inverse to each other (except of 2 bits)
	Eve	`1101000100100011` (1473x)	14	Identical to (one) key of Alice/Bob

Key Analysis
for the **dynamic** scenarios, **Triplet-Network**

Scenario		Most common keys (out of 1600 predicted)	#unique keys	Notes
Symmetric	**Alice/Bob**	1101000010111101 (1599x) 0010111101000010 (1x)	2	Inverse to each other
	Eve	1101000010111101 (1030x)	16	Identical to Alice/Bob
Symmetric-Varying-Speed	**Alice/Bob**	1011110100010011 (1599x) 0100001011101100 (1x)	2	Inverse to each other (except 1 bit)
	Eve	1011110100010011 (844x) 0100001011101101 (717x)	27	Inverse of each other, identical to Alice/Bob
Asymmetric	**Alice/Bob**	1101001100010001 (1600x)	1	Always same key
	Eve	1101001100010001 (956x)	24	Identical to Alice
Asymmetric-Reflector	**Alice**	0111110100101011 (1600x)	1	Always same key
	Eve	0111110100101011 (1129x)	20	Identical to Alice

Results Key Analysis

Main characteristics of keys: 

- Alice & Bob - always same key(s)
- Keys are practically **static** - only variate in 3-4 bits (out of 16 Bits)
- Keys are **flipped / inverted**

→ network seems to classify in two classes of keys

Conclusion

Our results:

Produced keys have desired Hamming Distance (low BER), but **not** random

- Randomness of keys - probably not evaluated extensively before
- Focus on Hamming Distance

Our theory:

- Key problem in **loss-function** of network:
  Randomness **not** included, only distance between keys

→ Method for solving all steps of PLKG in one step:
unfortunately does not seem to work as intended

→ Extracting randomness with neural network - not a trivial task

Thank you
for your attention.

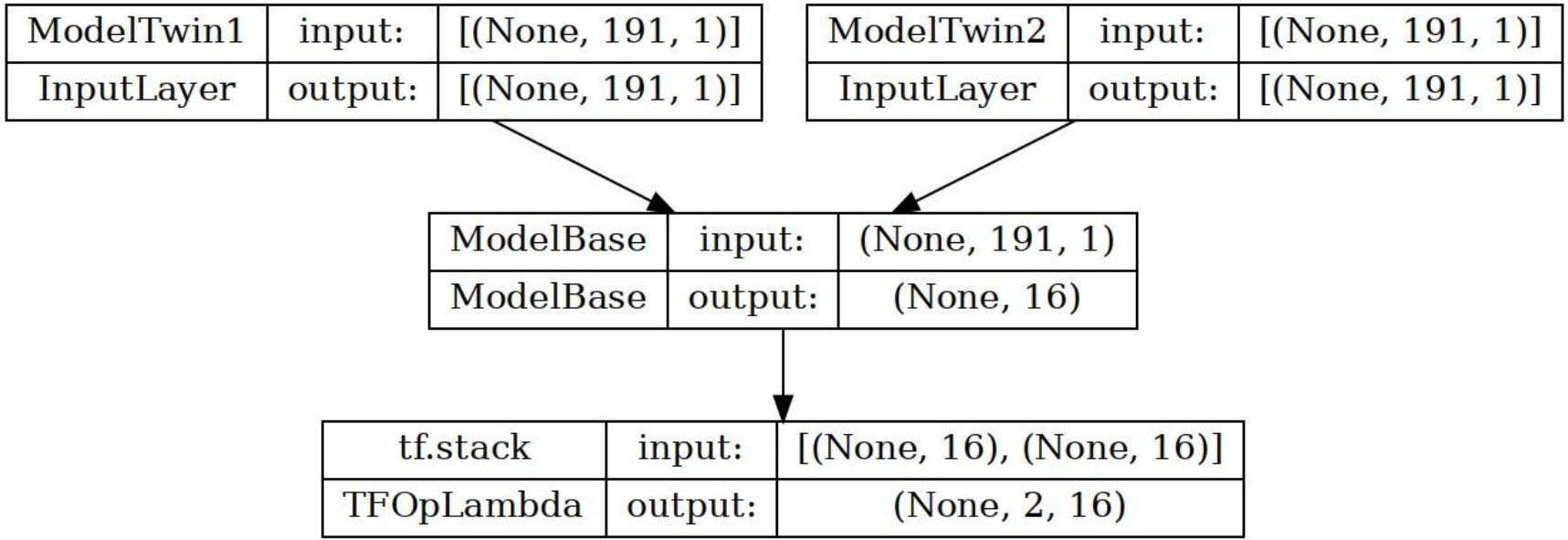
Sources

Original Method:
[0] P. Walther and T. Strufe, “Blind twins: Siamese networks for non-interactive information reconciliation,” in 2020 IEEE 31st Annual International Symposium on Personal, Indoor and Mobile Radio Communications, 2020, pp. 1–7

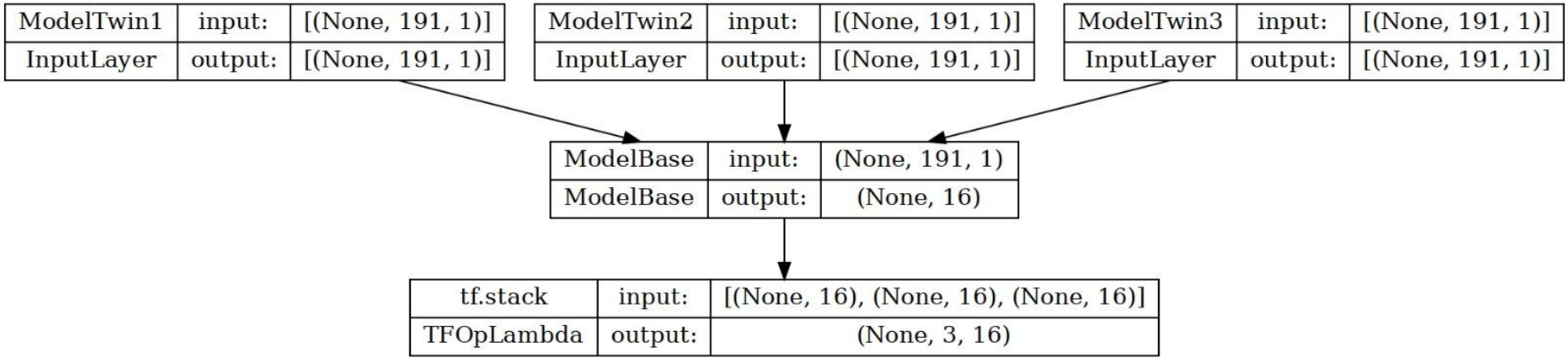
Our Re-Implementation:
[1] “Re-implementation of Siamese and Triplet Network”. Online: https://dud-scm.inf.tu-dresden.de/dud/ml-based-physical-layer-key-generation

Source for Dataset:
[2] P. Walter and R. Knauer and T. Strufe, “Ultra-Wideband Channel State Information and Localization for Physical Layer Security. IEEE Dataport, https://dx.doi.org/10.21227/0wej-bc28. 2021

Backup Slide
Siamese Network



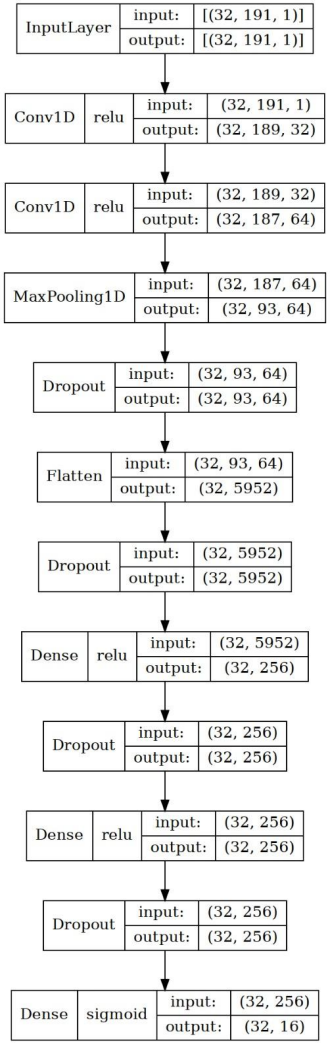
Backup Slide
Triplet Network



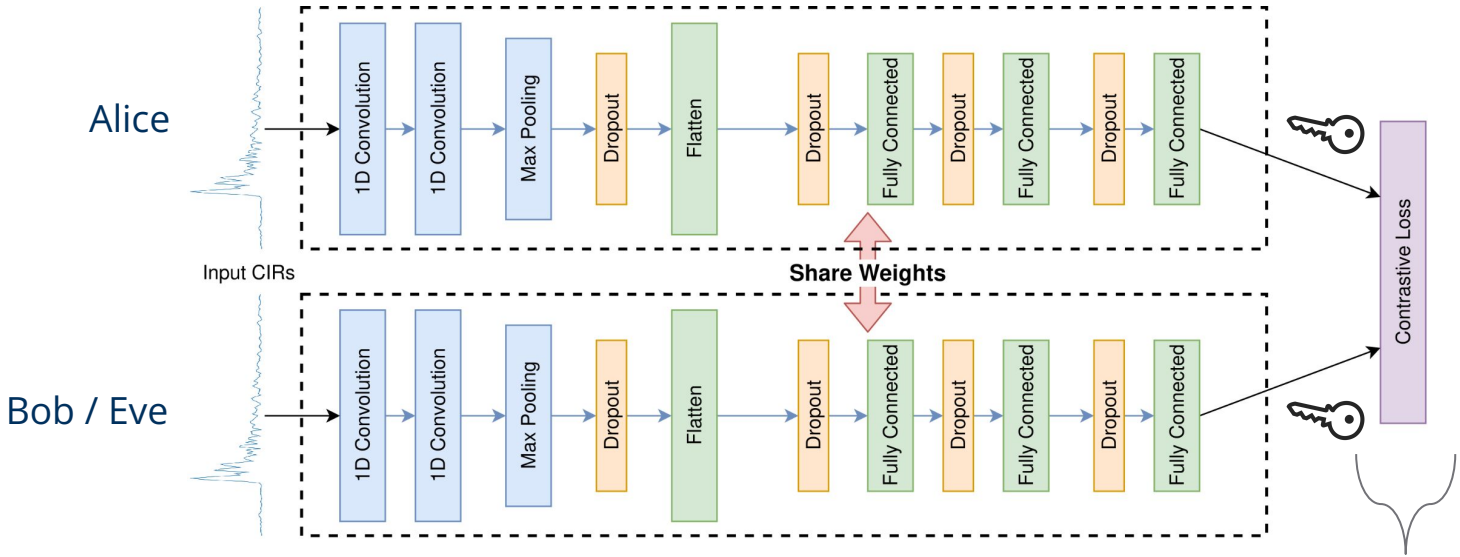
Backup Slide
Siamese / Triplet Neural Network

Architecture of the re-implementation:

- Optimizer: Nesterov Adam (default parameters)
- Batch size: 32
- Slice length / length of one CIR: 191



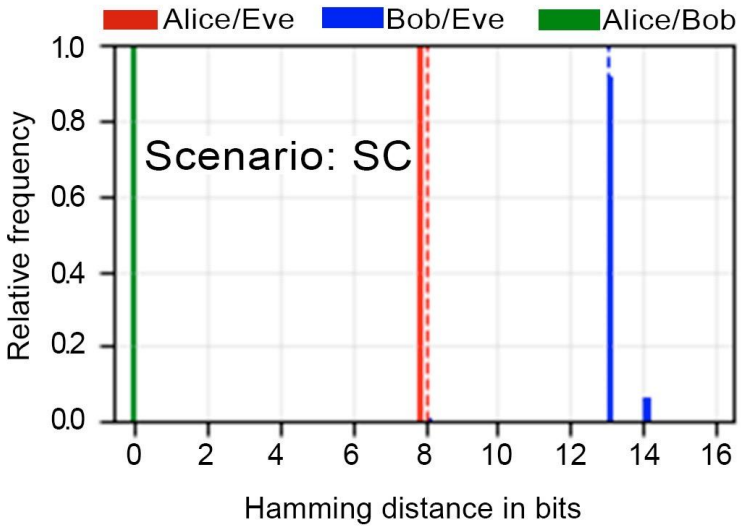
Backup Slide
Network Architecture: Siamese Twin Network

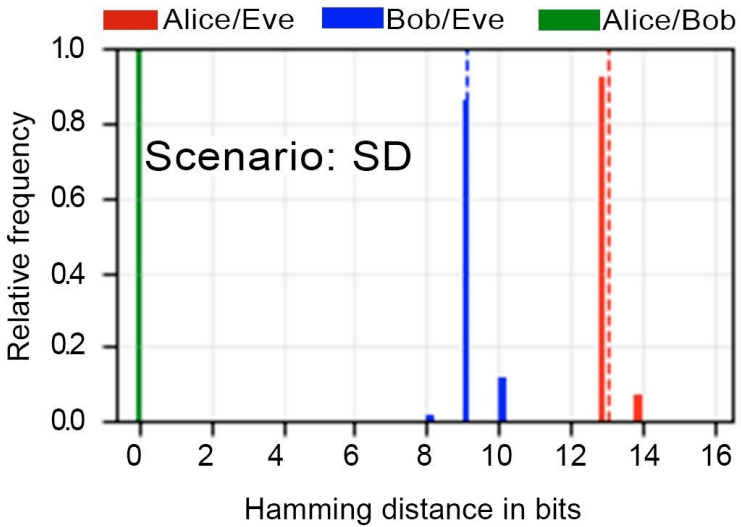


$$L(Y, X_1, X_2) = (1 - Y)\frac{1}{2}D^2 + Y\frac{1}{2}(\max(m - D, 0))^2$$

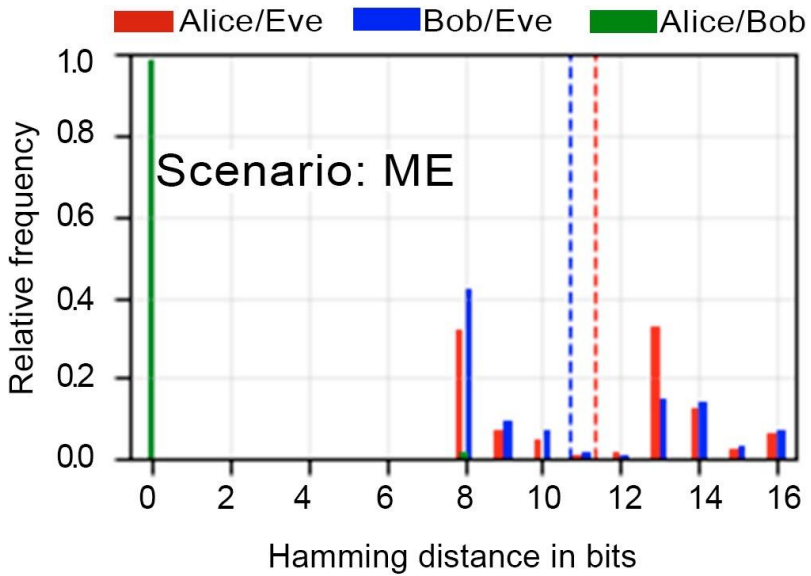
$$D(x, y) = y(1 - x) + (1 - y)x$$

Backup Slide
Original Results - Static Scenarios SC, SD
Walther et al. [0]





Backup Slide
Original Results - Dynamic Scenario ME
Walther et al. [0]



Backup Slide
Original Results - all dataset scenarios
Walther et al. [0]