

Towards Low-Power and Low Data-Rate Software-Defined Radio Baseband with RISC-V Processor for Flexibility and Security

18th CryptArchi Workshop - Porquerolles 2022
Porquerolles, France May 29- June 1, 2022



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Security of embedded systems?

- Physical Access
- Cryptography Implementation
- ...
- **Network Entry Point**

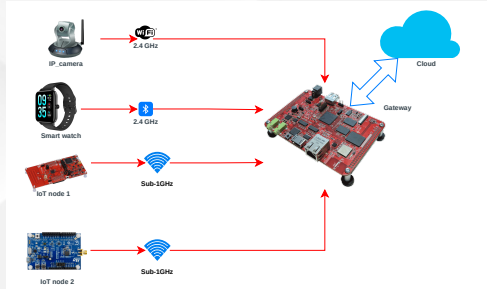


Figure: IoT architecture

- Main CPU for application user
- Peripherals and connectivity
- Integration of protection mechanism
- Isolation between Radio and user application

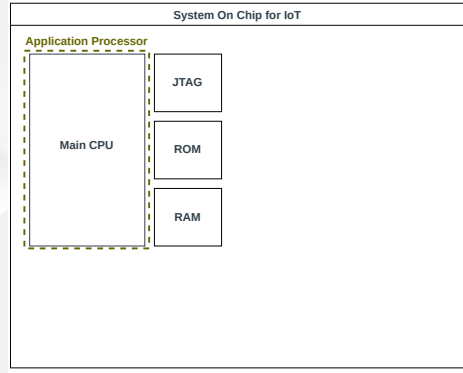


Figure: SoC IoT overview

Don't forget that SoC are integrating a wireless connectivity unit!

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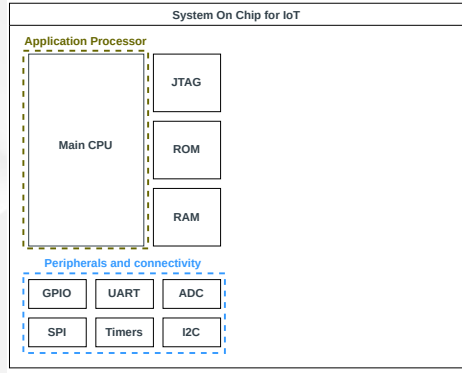


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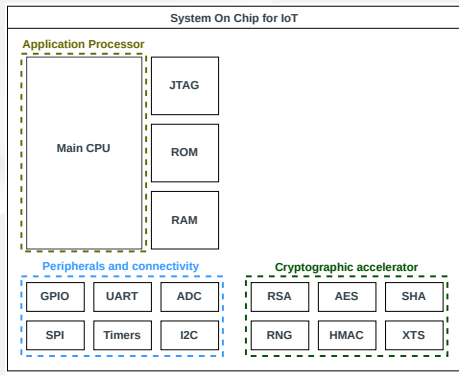


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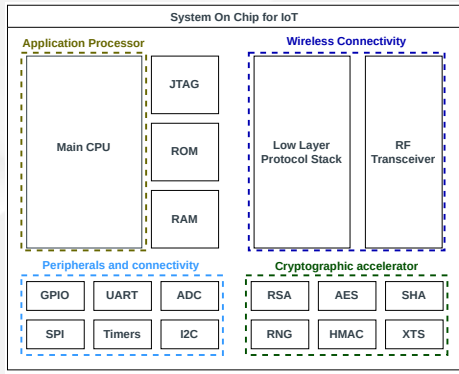


Figure: SoC IoT overview

Don't forget that SoC are integrating a wireless connectivity unit!

- 1 Threat model and countermeasures**
- 2 Proposed security mechanism: a multi-metrics HIDS**
- 3 Test-bed & Evaluation**

1 Threat model and countermeasures

- Threat Model
- Vulnerabilities in IoT
- Attack examples
- Attacks
- Security mechanisms & mitigation

2 Proposed security mechanism: a multi-metrics HIDS

3 Test-bed & Evaluation

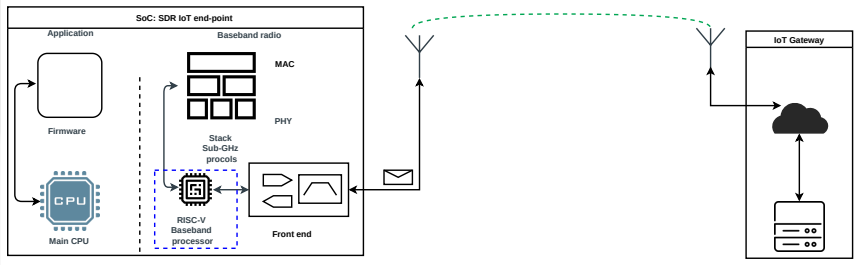


Figure: Potential Threat Model

Target : Remote Attacks

- Jamming Attack
- Logical Attacks: Packet Injection, ...

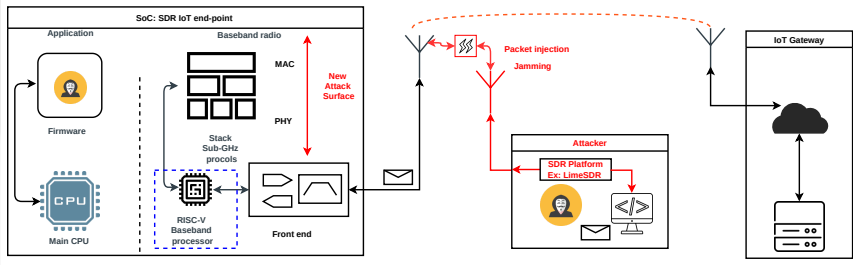


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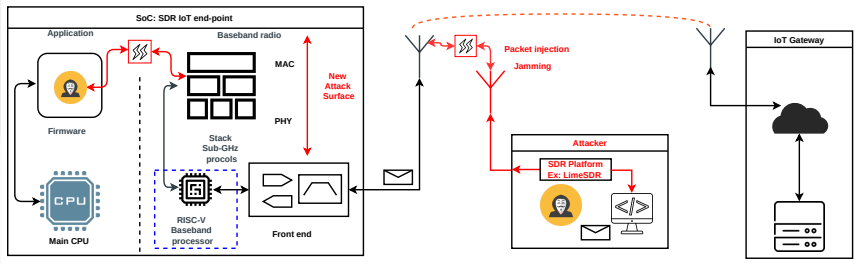


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Vulnerabilities in IoT

Vulnerability	AMNESIA33	BLEEDINGBIT	LoRaDawn
Number of CVEs	33 [Labs, 2020]	2 [Seri, Benn (ARMIS et al., 2019)]	2 [ten, 2020]
Where ?	Poor Software Development	Masking Error, OAD	OTAA Process, 32bit Gateway
Target Device	ulP, FNET, picoTCP, NuTNet	AP with TI BLE	LoRaMac-node, LoRa Basics Station
Stack Layer	Physical /MAC	MAC	MAC
Stack / protocol	TCP/IP / IEEE 802.15.4	BLE	LoRaWAN
Exploit	RCE, DoS, Steal Data	Packet injection, RCE	DoS, RCE, Heap UAF

Table: A set of three Groups of vulnerabilities in IoT and their features

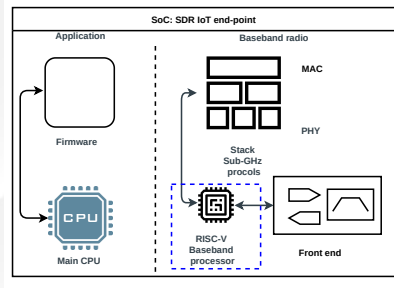


Figure: SoC for IoT with wireless connectivity

Example of Exploit : InjectBLE [Cayre et al., 2021]

- Vulnerabilities: **Long synchronization time** between Slave and Master BLE in connection step
- Exploit: Packet injection (**Hijacking slave and master, MITM**)
- **InjectBLE Firmware**
- **Mirage framework**
- Used BLE module: **nRF52840-dongle**



Figure: nRF52840-dongle : <https://www.nordicsemi.com/>

Example of Exploit : Main in the middle (MITM) attack

We reproduce the MITM attack using two modules from mirage framework in order to sniff packets between master and slave: (**ble_hijack** and **ble_maste**)

- **ble_master**: Mobile App
- **ble_slave**: Led strip
- **Attacker**: Laptop with nRF52840-dongle

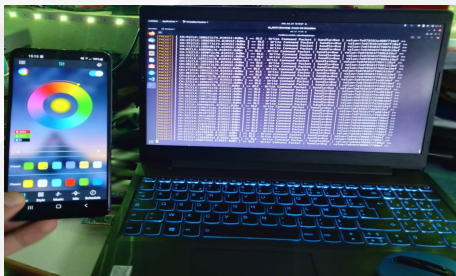


Figure: Sniffing packet exploit

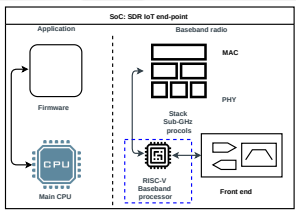


Figure: SoC for IoT

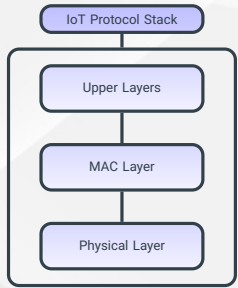


Figure: IoT protocol stack layers

E (Exploited Layer) T (Targeted Layer)

Ref	Protocol	Attack	PHY	MAC	Upper	Exploit
[Cayre et al.,]	Zigbee	Wazabee	E	E/T	T	DoS, packet injection
[Aras et al.,]	LoRaWAN	Selective Jamming	E	E/T	T	DoS, Wormhole
[Hessel et al.,]	LoRaWAN	Spoofing	E	E/T	-	DoS
[Avoine and Ferreira, 2018]	LoRaWAN		-	T	T	replay, decrypt, DoS
[Cayre et al., 2021]	BLE	InjectBLE	E	E/T	T	MITM, Sniffing
[Zhang et al., 2020]	BLE	Downgrade	-	-	T	DoS, MITM
[Santos et al., 2019]	BLE	Injection-free	-	-	E/T	DoS, MITM
[Antonioni et al., 2020]	BT/BLE	Key.nego downgrade	-	E/T	E/T	Decrypt packet, MITM

Table: Security SoA IoT Low Data rates protocols (Sub-GHz, Zigbee, BLE)

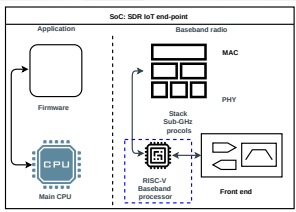


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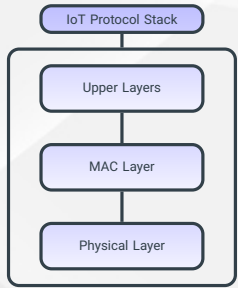


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Features	CC1356	CC1352R1	STM32WL54CC
Sec. Boot (protection)	✓	✓	✓
Cryptography (protection)	✓	✓	✓
OTA (Update)	✓	✓	✓
Heap ASLR (protection)	✗	✗	✗
Monitoring (detection)	✗	✗	✗
DIFT (hard. monitor)	✗	✗	✗
Code instrumentation (protection)	✗	✗	✗
Anomaly/Intrusion detection	✗	✗	✗

Table: Platform security features comparison

Security Mechanisms

- Confidentiality, Integrity and availability
- Protection mechanisms
- Update & Over the air Mechanisms
- **Monitoring & Detection Mechanisms**

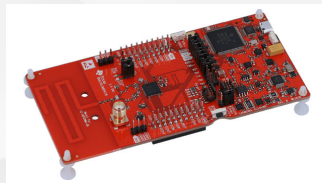


Figure: CC1352R1 : SoC for IoT

1 Threat model and countermeasures

2 Proposed security mechanism: a multi-metrics HIDS

- Motivation and contribution
- Intrusion Detection System Taxonomy
- Host based IDS in state of the art
- Towards a multi-level metrics HIDS

3 Test-bed & Evaluation

Motivation

- Remote attacks detection on wireless connectivity of IoT SoC
- The necessity of a monitoring detection mechanism that captures system behavior and identifies attacks.

Contribution: Intrusion Detection System (IDS)

- Acquisition, Analyze and Identification, warn or block attacks

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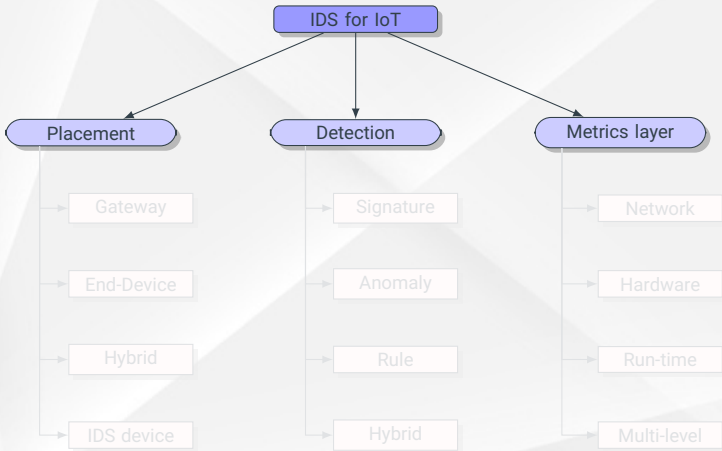


Figure: IDS taxonomy for IoT environment

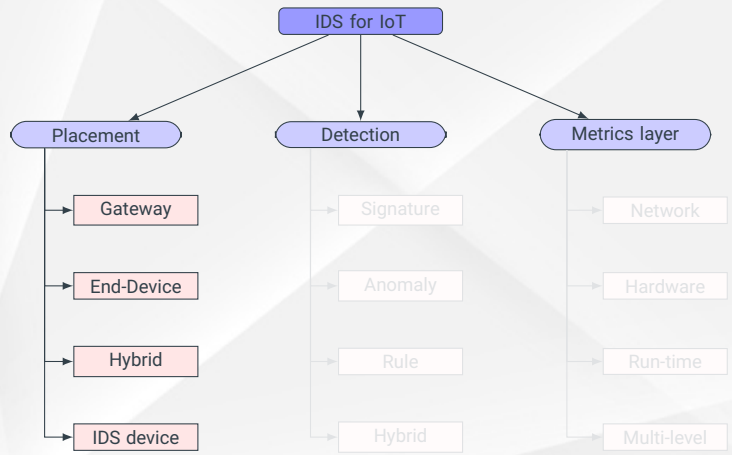


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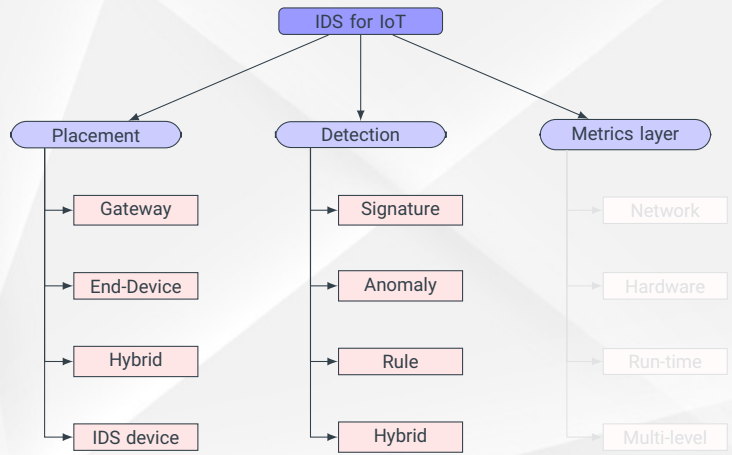


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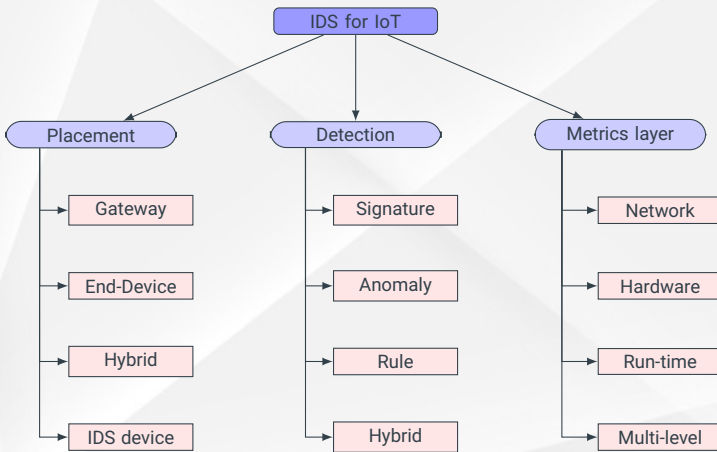


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What are the accurate metrics to record for an HIDS?

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[Zhang et al., 2013]	RSSI	TS	TS	-	-	integrity	SDR	B	D
[Sousa et al., 2017]	-	P	-	-	-	DoS	Analyze & store	S	RC
[Kasinathan et al., 2013]	-	P	-	-	-	DoS, Jamm	SURICATA	S	D
[Eskandari et al., 2020]	Traffic	P	-	-	-	P:inject	GUI LINUX	S	G
[Raza et al., 2013]	-	P	-	-	-	Rout, Snik	IDS + min.FW	B+S	H
[Saeed et al., 2016]	-	-	Sensor	IMA	-	P:inject, DoS	C.Instru + ML	B	G
[Gassais et al., 2020]	-	-	-	CTF	-	DD/DoS	Tracing + ML	S	H
[Bourdon et al., 2021]	-	-	-	HPC	-	P:inject	Tracing + ML	B	H
[Breitenbacher et al., 2019]	-	-	-	-	SC	0-day, DoS	LKM + Whitelist	B	RC

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- **MAC**(Mac layer): **TS**(Time series), **P**(Packet Header)
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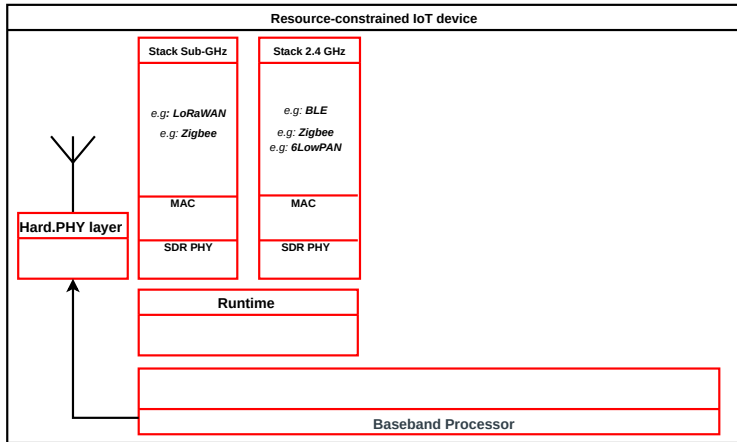
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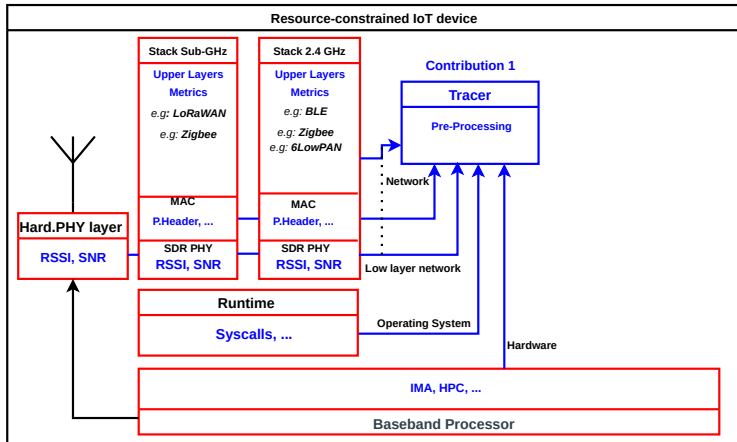
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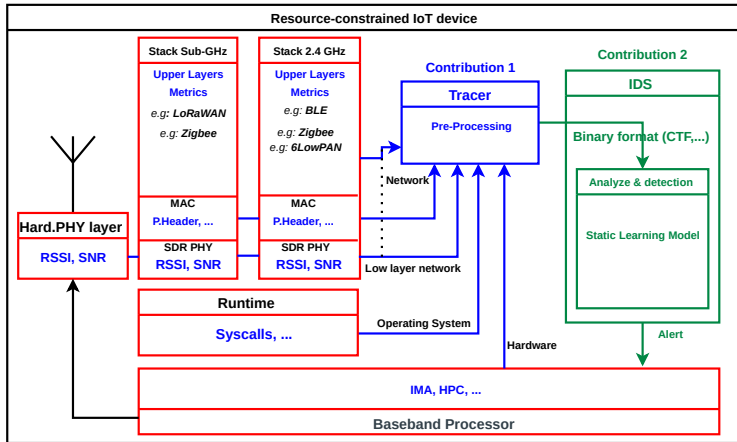
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Wireless connectivity block diagram with IDS



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Wireless connectivity block diagram with IDS

- 1 Threat model and countermeasures
- 2 Proposed security mechanism: a multi-metrics HIDS
- 3 Test-bed & Evaluation**
 - Objective
 - Test-bed
 - Preliminary results
 - Conclusion

- **Proposed Hardware :**
 - **CV32E41P** RISC-V Processor for handling the wireless connectivity
 - Record Hardware Performance Counters (HPC) from CV32E41P by **HPMtracer** (Hardware block)

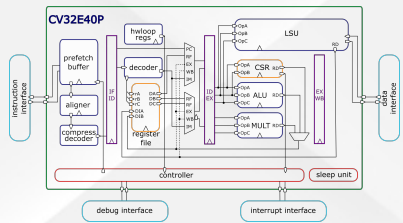


Figure: CV32E41P/40P block diagram

- **Scenario**
 - Reproduction of simple buffer overflow exploit on software running on wireless connectivity
 - Record HPC values per each packet network

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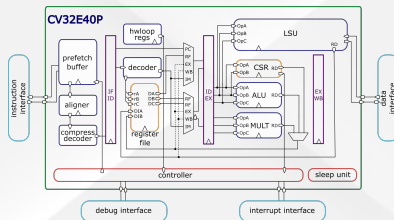


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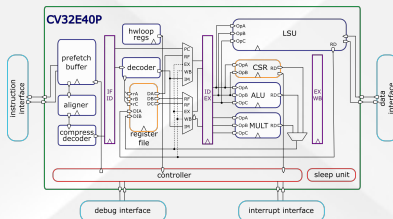


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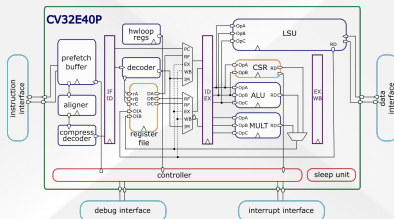


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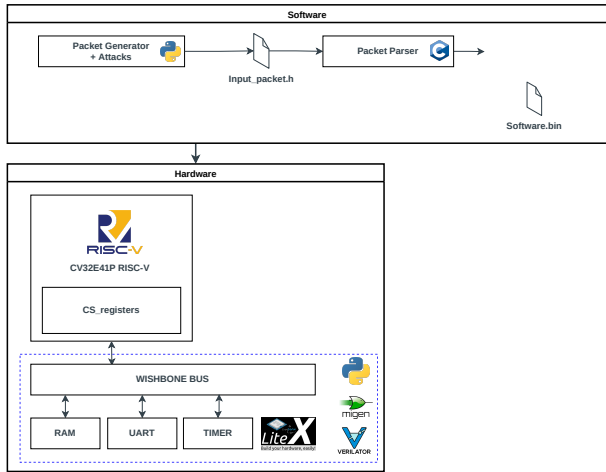


Figure: Test-bed block diagram

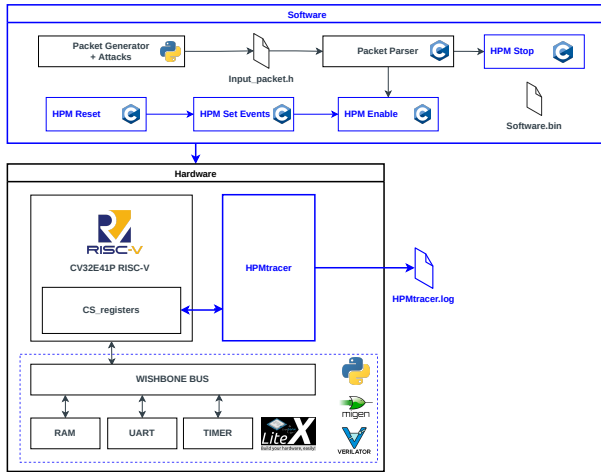


Figure: Test-bed block diagram

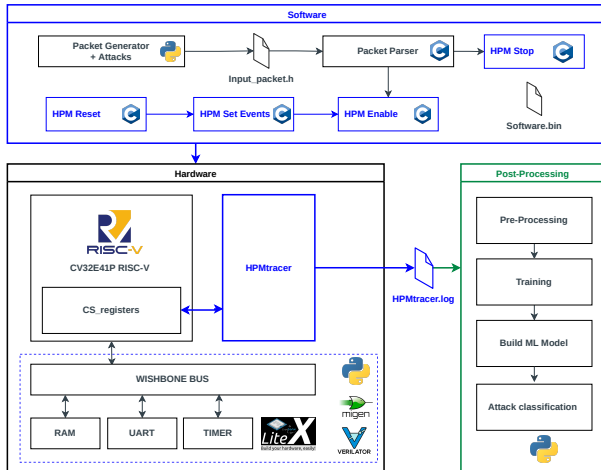


Figure: Test-bed block diagram

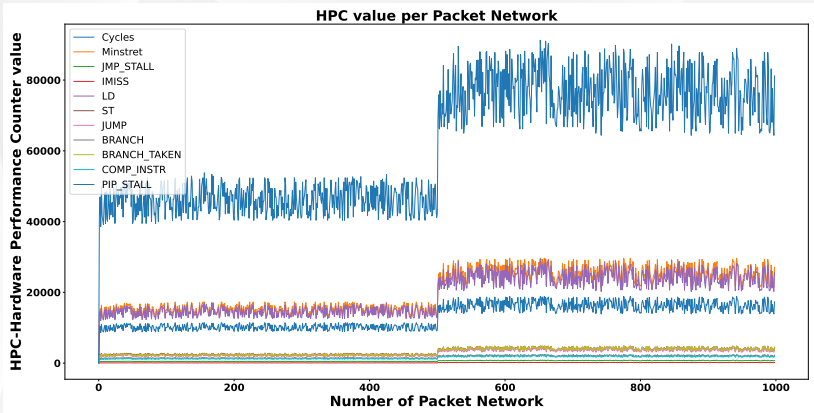


Figure: Dataset from HPC monitors

This table shows the evaluation results of the comparison of several classification algorithms.

Method	Accuracy	Precision	Recall	F1 score
Nearest Neighbors	0.998	0.995	1.00	0.998
Linear SVM	0.998	0.995	1.00	0.998
RBF SVM	0.765	1.000	0.550	0.710
Gaussian Process	0.887	1.000	0.785	0.879
Decision Tree	0.998	0.995	1.000	0.998
Random Forest	0.998	0.995	1.000	0.998
Neural Net	0.583	0.977	0.206	0.340
AdaBoost	0.998	0.995	1.000	0.998
Naive Bayes	0.995	0.995	0.995	0.995
QDA	0.995	0.995	0.995	0.995

- Interesting Results
- An in-depth study to follow

- **Ongoing work**

- New approach for monitoring and detecting software attacks from a network entry point.
- Test-bed to detect buffer overflow using hardware counters.
- Promising results of machine learning classification algorithms.

- **Future work**

- Tracer Implementation.
- Lightweight IDS Detection Module on Co-processor.
- Tracer & IDS Evaluation (**Detection, Benchmarks, Overhead, Power consumption**).

THANK YOU

Towards Low-Power and Low Data-Rate Software-Defined Radio Baseband with RISC-V Processor for Flexibility and Security

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Porquerolles, France May 29- June 1, 2022



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