POLISH NATIONAL AGENCY FOR ACADEMIC EXCHANGE

SDSU | San Diego State University

P4 Based Software Defined Network - Communication Platform for Airborne Computing

Towards Networked Airborne Computing in Uncertain Airspace: A Control and Networking Facilitated Distributed Computing Framework

Poznan Workshop, October 2024

POLITECHNIKA POZNAŃSKA

Agenda:

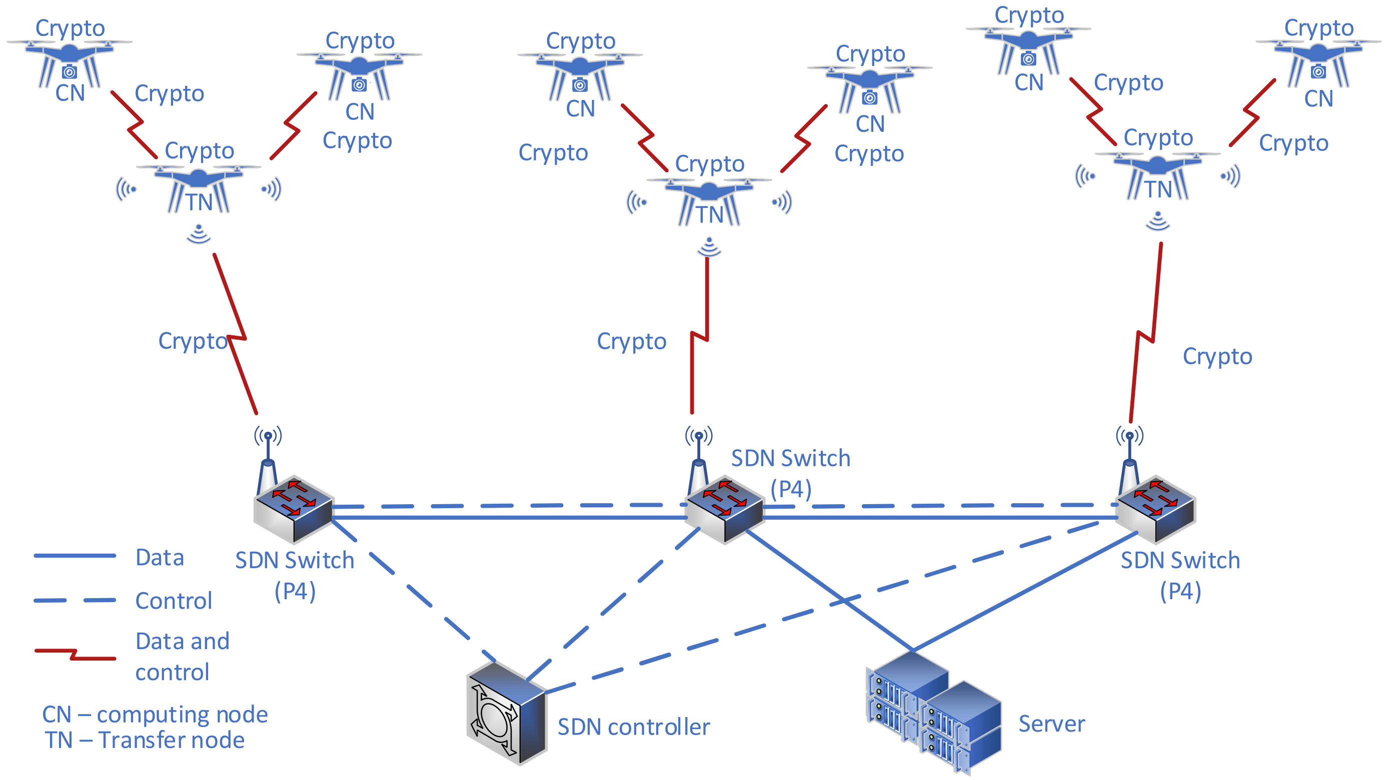
- System Architectures
- Definitions
- P4 - Programming Protocol-independent Packet Processors
- Functional structure
- Addressing
- In-bound Network Telemetry
- Moving target Defense

POLITECHNIKA POZNAŃSKA

System Architectures

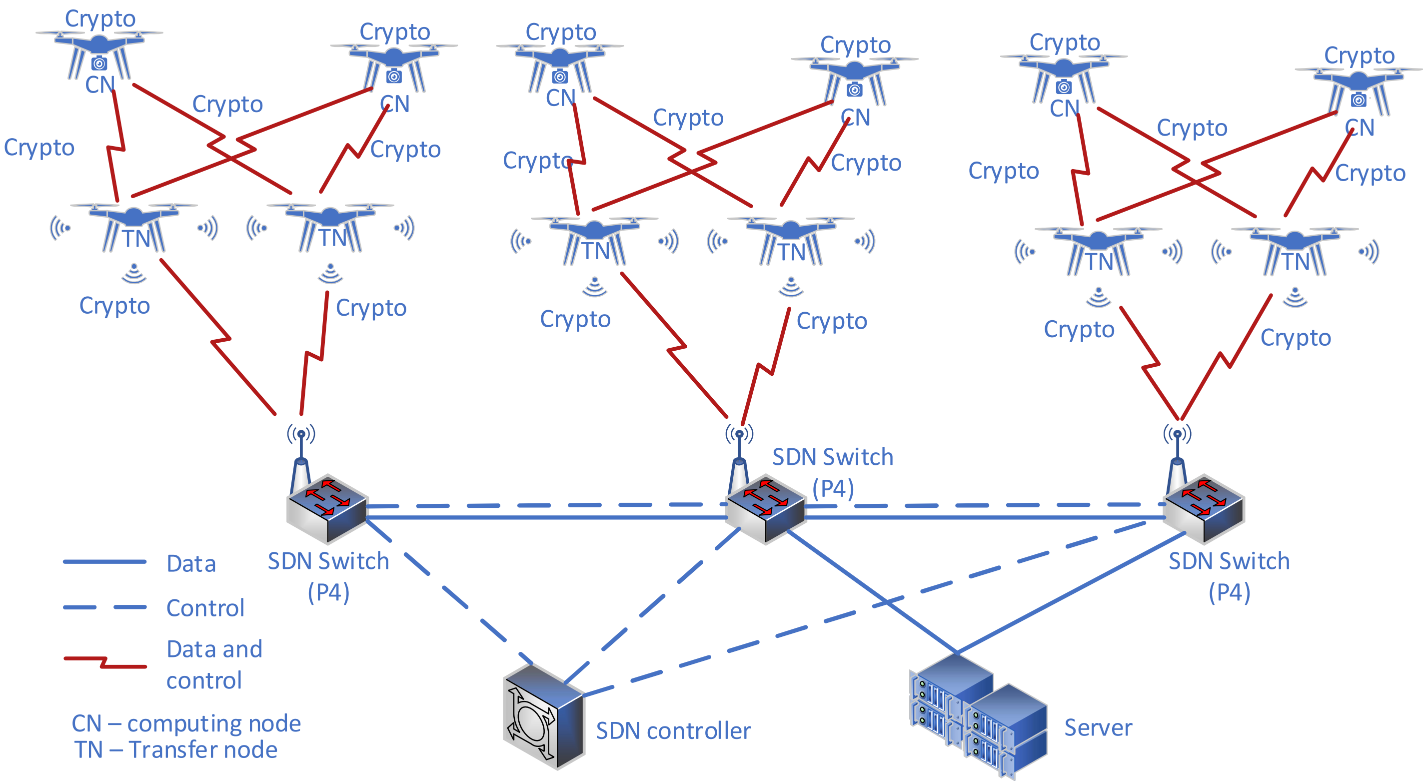
POLITECHNIKA POZNAŃSKA

Hierarchical architecture



POLITECHNIKA POZNAŃSKA

Hierarchical architecture - MTD

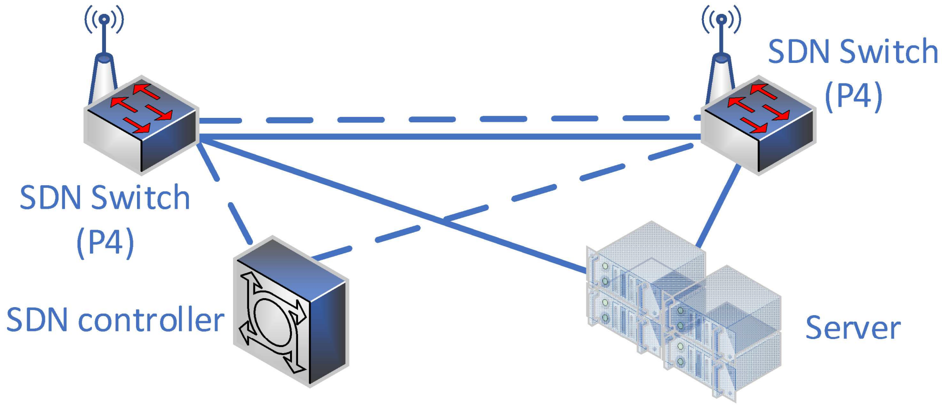


POLITECHNIKA POZNAŃSKA

Definitions

POLITECHNIKA POZNAŃSKA

Terestial devices



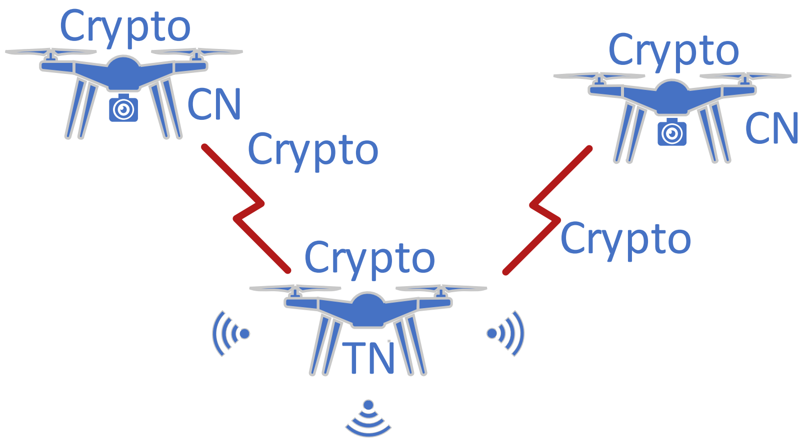
- **Server** – A device responsible for assigning tasks to drones. It provides data for processing and makes decisions regarding the operation of the AirBorn computing system.
- **SDN Switch** - A switch programmable in the P4 language (Programming Protocol-independent Packet Processors) that enables communication with other SDN switches and radio transmitters. The ability to program the data path allows for the creation of new functions for existing protocols.
- **SDN Controller** – A device that provides control data to SDN switches. It offers an interface to the network application layer and supplies statistical data on drone workloads collected via INT (In-band Network Telemetry).

POLITECHNIKA POZNAŃSKA

UAVs

- **CN** – Computing Node. Its primary function is to perform calculations according to the tasks assigned by the server.

- **TN** – Transit Node. Its role is to distribute messages to the CN. It is a component of the MTD (Moving Target Defense) application.



Channel definitions

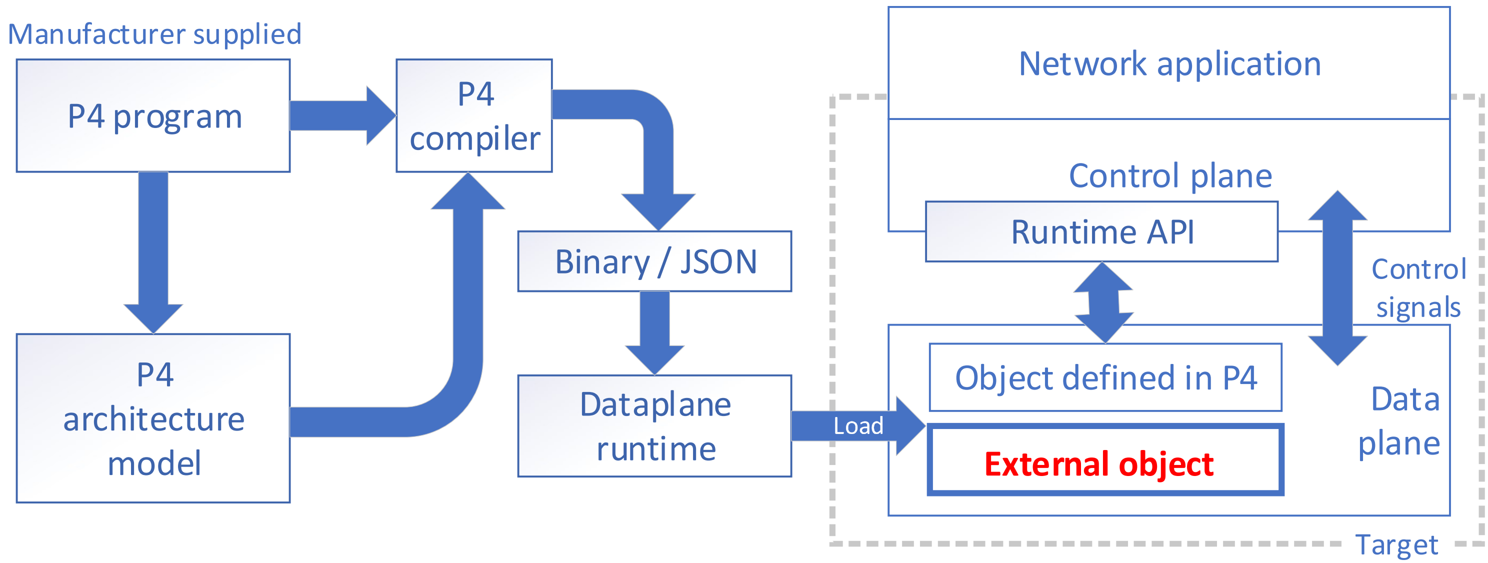
- **ChTD** - Tactical Data Channel – used to transmit data necessary to perform tasks specified by the server.
- **ChT** - Task Assignment Control Channel – used to inform drones about the tasks that need to be performed.
- **ChINT** - Telemetry Data Channel – responsible for transmitting individual reports (from CN) or aggregated reports (from TN).
- **ChP4** - Control Channel for managing the operation of TN, CN, and SDN switches.
- **ChCrypto** - Channel used for the exchange of cryptographic data.
- **ChUAV** - Channel controlling drone operations (not included in the project).

POLITECHNIKA POZNAŃSKA

P4
Programming Protocol-independent Packet Processors

POLITECHNIKA POZNAŃSKA

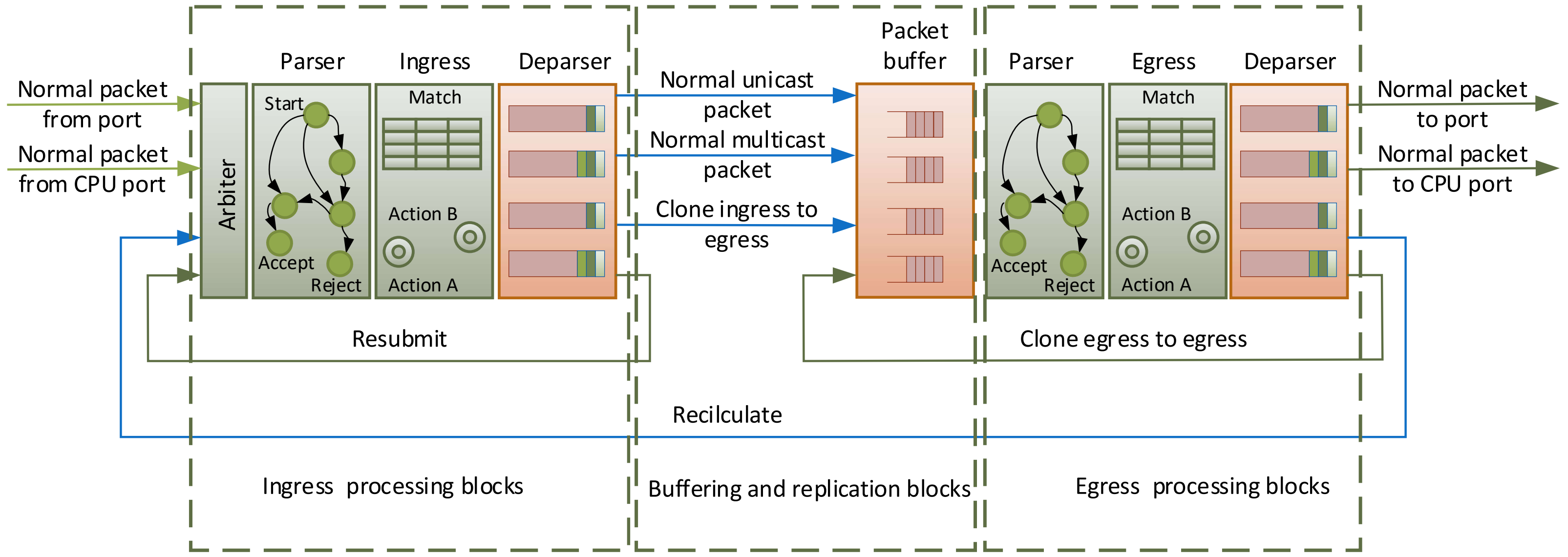
Programming a target with P4



PISA (Protocol-Independent Switch Architecture): Flexible Match+Action ASICs	Intel Flexpipe, Cisco Doppler, Cavium (Xpliant), **Intel/Barefoot Tofino**, …
NPU (Network Processor Unit)	EZchip, Netronome
CPU	Open Vswitch, eBPF, DPDK, VPP
FPGA	Xilinx, Altera

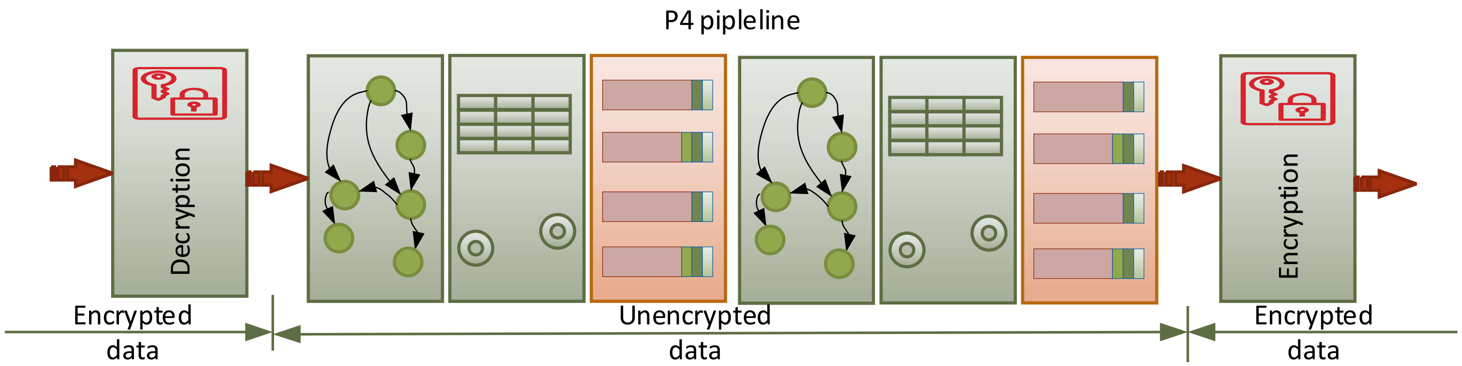
POLITECHNIKA POZNAŃSKA

PSA – Portable Switch Architecture (P4 pipeline)



POLITECHNIKA POZNAŃSKA

Interaction P4-Crypto Transparent Mode



Advantages:

- P4 and Crypto are developed independently
- Easier implementation at the program level

Disadvantages:

- Low performance
- Integration issues at the physical level (interfaces incompatibility)

POLITECHNIKA POZNAŃSKA

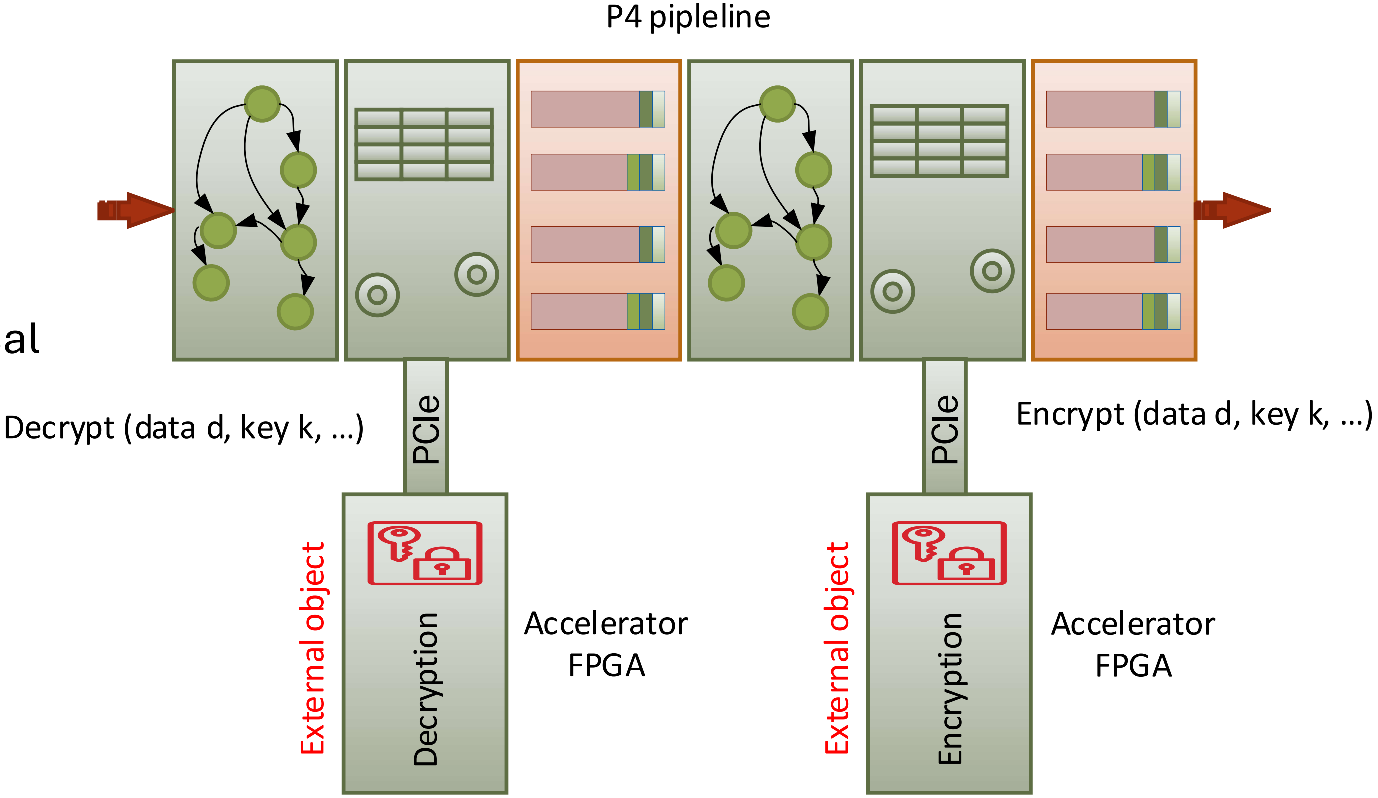
Interaction P4-Crypto Cooperation Mode

Advantages:

- High performance
- No integration at the physical layer level

Disadvantages:

- Difficult implementation in FPGA (Verilog, VHDL)

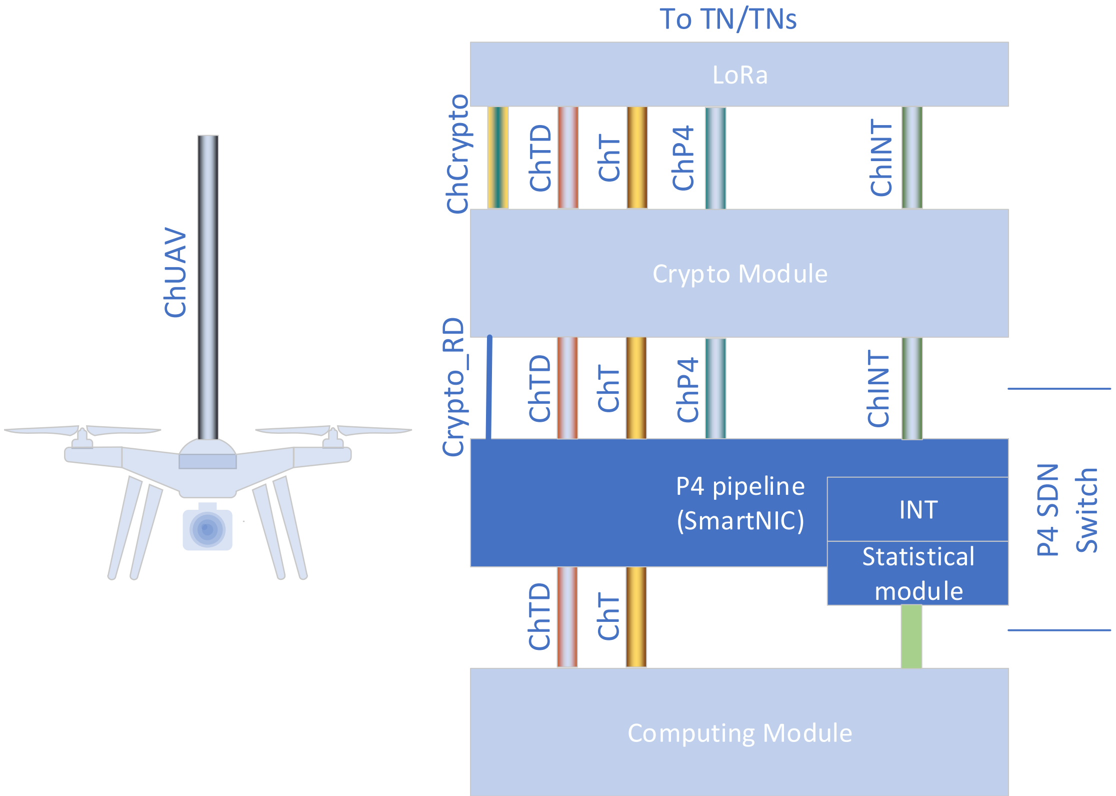


POLITECHNIKA POZNAŃSKA

Functional structure

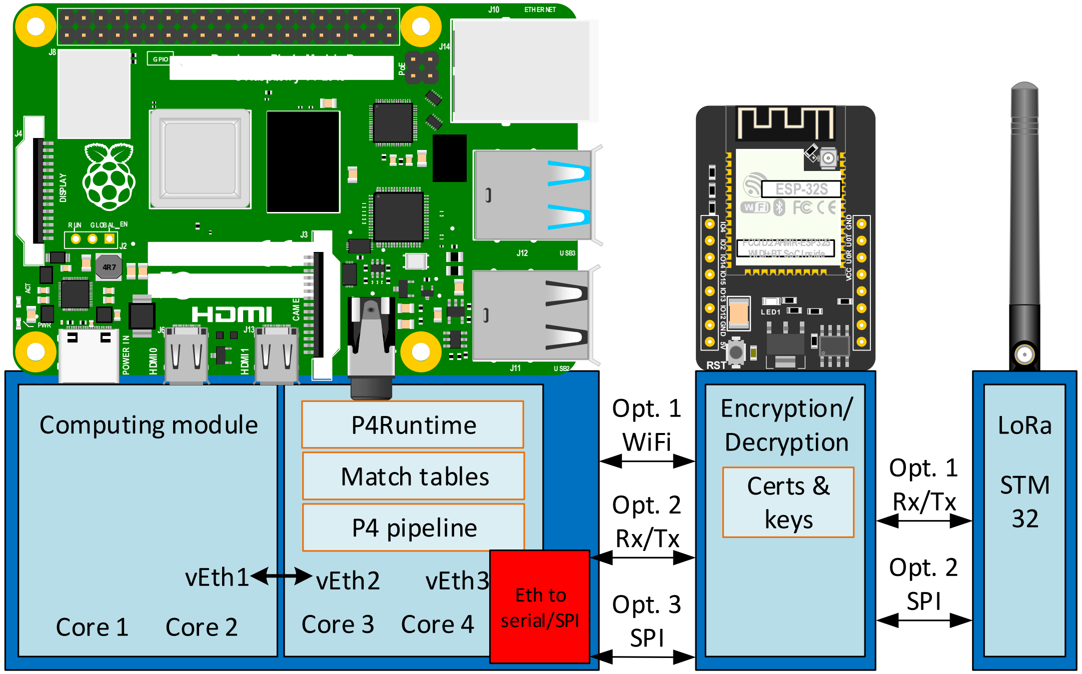
POLITECHNIKA POZNAŃSKA

Computing Node



POLITECHNIKA POZNAŃSKA

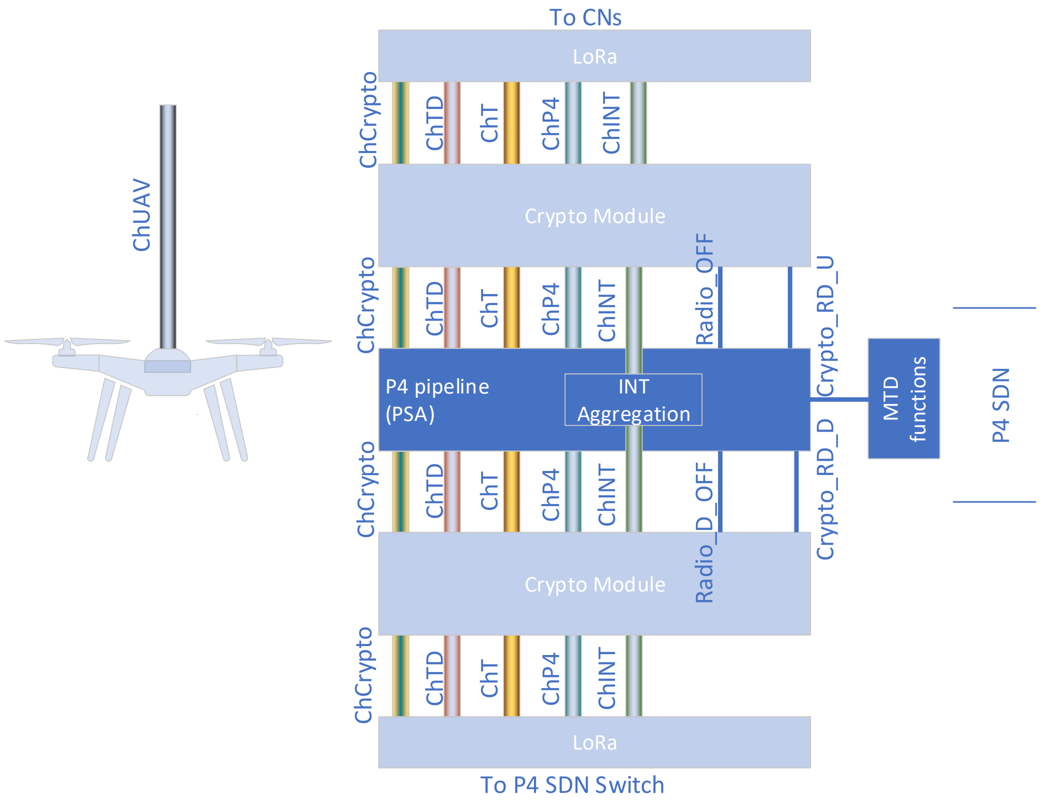
Computing Node - implementation



- The P4 architecture does not natively support interfaces other than Ethernet. The use of Rx/Tx (Serial) or SPI requires an additional converter (hardware or software).

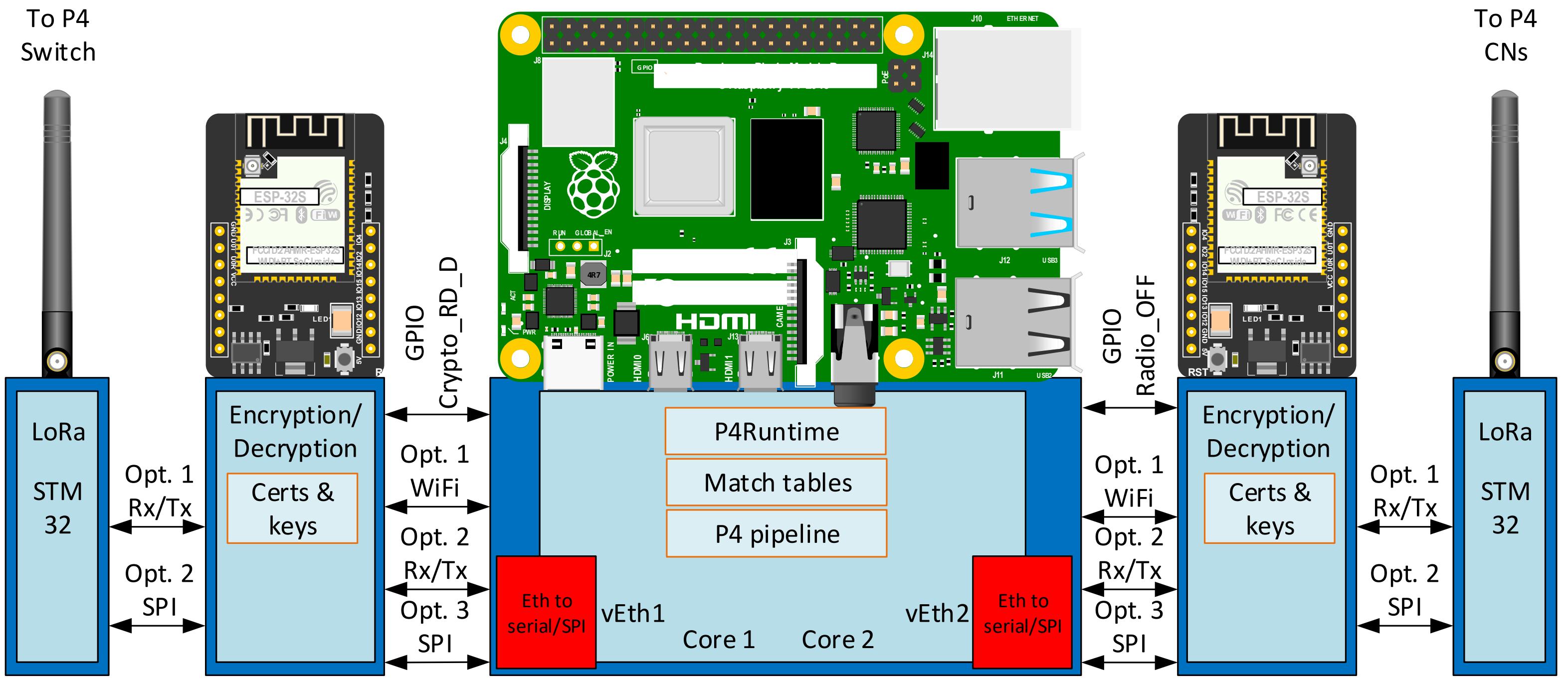
POLITECHNIKA POZNAŃSKA

Transfer Node



POLITECHNIKA POZNAŃSKA

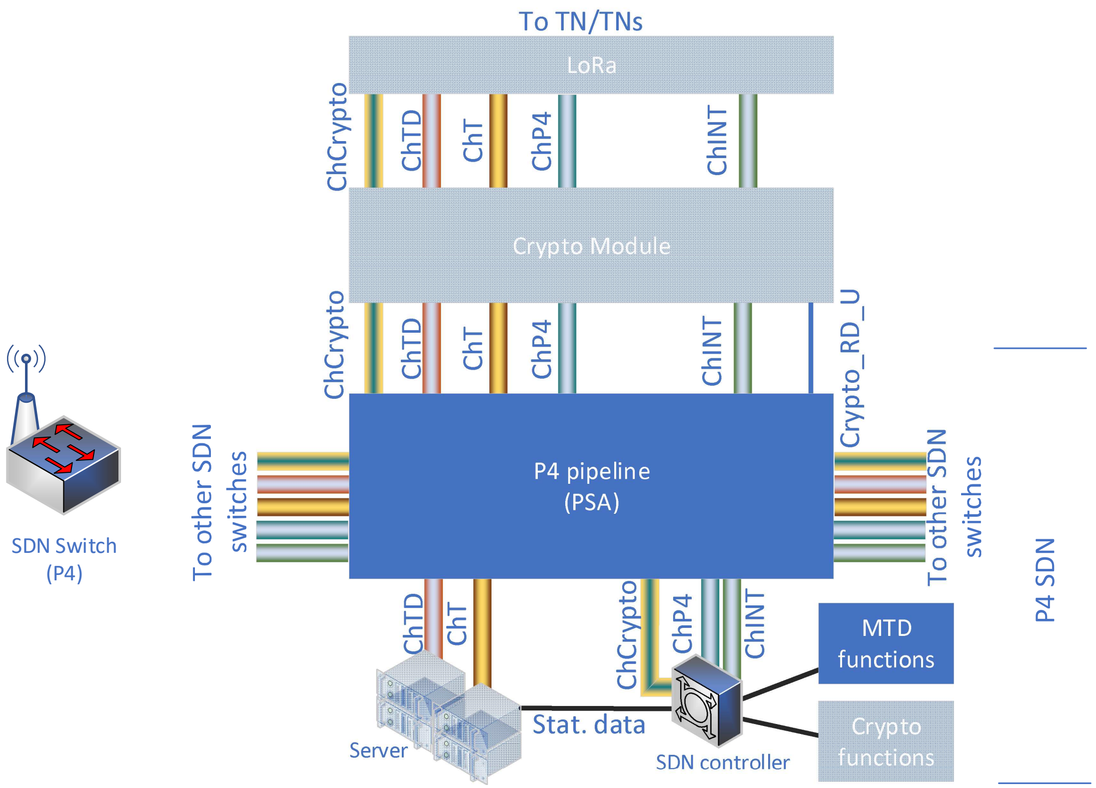
Transfer Node - implementation



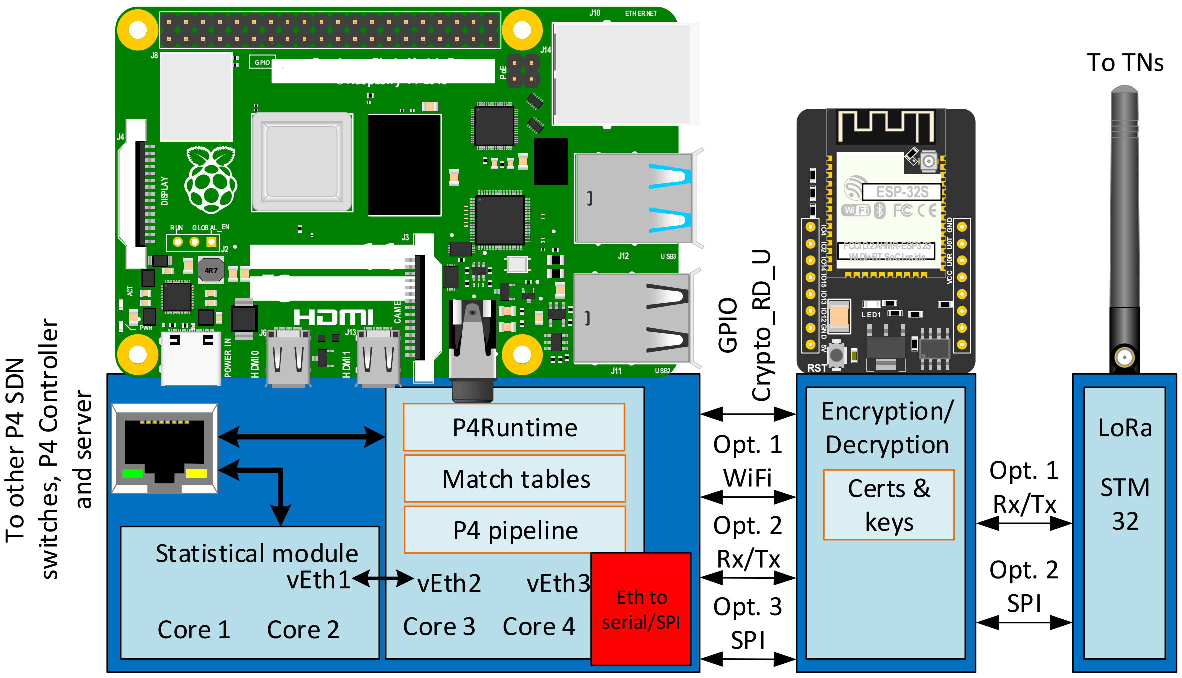
- The P4 architecture does not natively support interfaces other than Ethernet. The use of Rx/Tx (Serial) or SPI requires an additional converter (hardware or software).

POLITECHNIKA POZNAŃSKA

SDN Switch



SDN Switch - implementation



- The P4 architecture does not natively support interfaces other than Ethernet. The use of Rx/Tx (Serial) or SPI requires an additional converter (hardware or software).

POLITECHNIKA POZNAŃSKA

Addressing

POLITECHNIKA POZNAŃSKA

TCP/IP Protocol Stack Addressing

P4 allows for the use of any protocol stack (other than TCP/IP or even raw data blocks), but to simplify the implementation, it is suggested to use the TCP/IP stack, particularly the IP and TCP protocols (to avoid issues with message loss and duplication). Since implementing all the necessary mechanisms of the IP protocol would be a very time-consuming solution, it is essential to store all MAC addresses in device tables (to avoid implementing the ARP protocol).

The following addressing principles are proposed:

1. P4 SDN switch has an individual network IP address.
2. P4 SDN switch, as well as the CNs and TNs it manages, are in the same IP network.
3. TNs and CNs have a unique IP address.
4. Each channel is established in a bidirectional mode.
5. Channels are distinguished based on TCP port numbers.

POLITECHNIKA POZNAŃSKA

In-bound Network Telemetry

POLITECHNIKA POZNAŃSKA

The Use of INT in the Project

- In-Band Network Telemetry is specified by the P4 language community. It has been designed to provide very detailed information on network behavior by inserting a small amount of information directly into packets passing through network devices. Of course, devices involved in transmitting INT messages must have this functionality implemented. However, this enables probing functionality for potentially every packet, including customer traffic. INT is a very powerful debugging tool, capable of measuring and recording each tagged packet sent through the network.
- In this case, we will use INT mechanisms to carry information about the status of drones and their computational load.

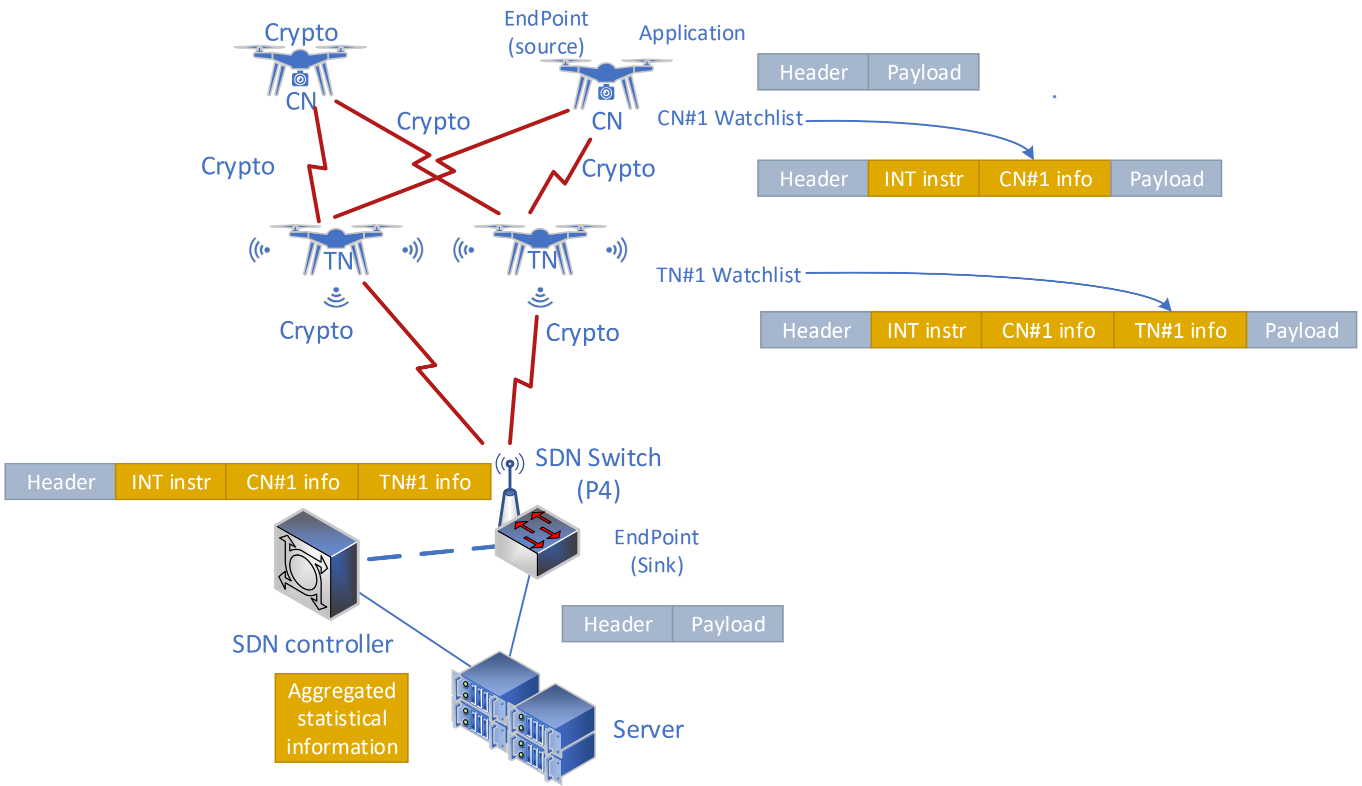
INT Modes

Original data packets are monitored and may be modified to carry INT instructions and metadata. There are three variations based on the level of packet modifications.

- INT-XD (eXport Data): INT nodes directly export metadata from their dataplane to the monitoring system based on the INT instructions configured at their Flow Watchlists. No packet Modification is needed.
- INT-MX (eMbed instruct(X)ions): The INT Source node embeds INT instructions in the packet header, then the INT Source, each INT Transit, and the INT sink directly send the metadata to the monitoring system by following the instructions embedded in the packets.
- **INT-MD(eMbed Data):** In this mode both INT instructions and metadata are written into the packets. This is the classic hop-by-hop INT where 1) INT Source embeds instructions, 2) INT Source & Transit embed metadata, and 3) INT Sink strips the instructions and aggregated metadata out of the packet and (selectively) sends the data to the monitoring system.

POLITECHNIKA POZNAŃSKA

INT concept



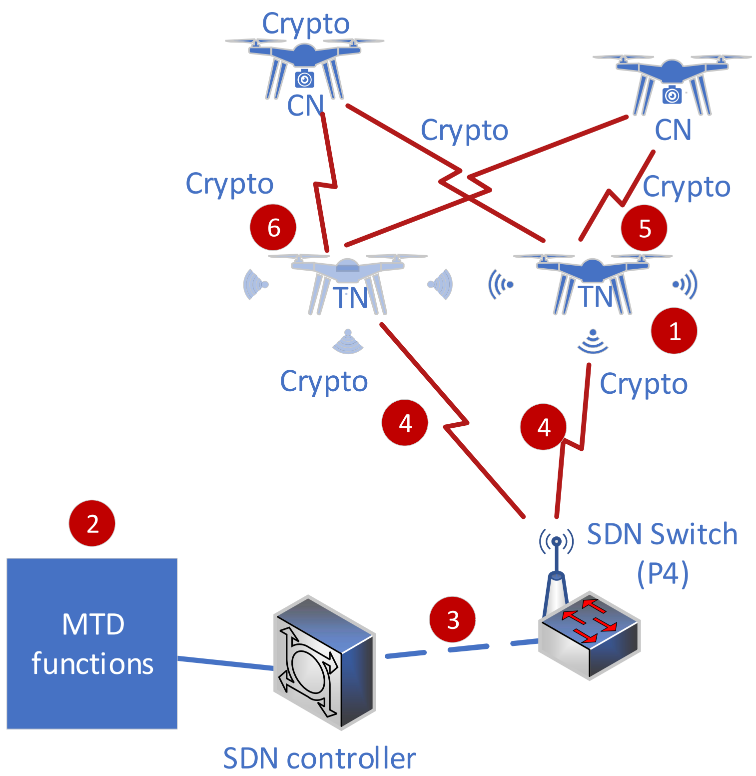
MTD - Moving target Defense

Selection of the Protected Element

- Techniques of Moving Target Defense (MTD) make reconnaissance-based attacks more difficult. They can be applied to any network element (host, switch, router, program, OS, etc.), depending on which element is being protected.
- The proposed target for protection in this project is quite unusual, as TN drones will be protected. Since CN drones are constantly moving and do not continuously transmit data, they are quite difficult to locate. We can say that the MTD technique is natively applied to them. However, TN drones are continuously transmitting, both towards the P4 SDN switch and to the CNs. They become easy to detect with the use of directional antennas and thus easy to destroy.
- The proposal is that CNs within the area of a single P4 SDN switch should be supported by several TNs. However, at any given moment, only one TN will be in an active state (transmitting and receiving from CNs), while the others will only be collecting data (both from the P4 SDN switch and from the CNs). At a random or cyclic moment, the MTD control mechanisms will indicate which drone will transition to the active state. The drone previously in the active state will stop transmitting after emptying its transmission buffers and will change its location.

POLITECHNIKA POZNAŃSKA

The operating principle of the proposed MTD mechanism



1. At any given moment, only one TN is in an active state, while the remaining TNs are in a listening state.
2. At random moments or cyclically, the MTD function sends a message, which is inserted into all data streams, about the change of the active TN. Duplicating this information across all channels allows the detection of the moment when they are emptied and the sending of a message to the cryptographic/radio part about their shutdown.
3. The message is delivered to the P4 SDN switch.
4. The message is delivered to all TNs.
5. The active TN switches to the listening state and initiates the relocation procedure.
6. The drone indicated by the MTD function becomes active, i.e., it starts transmitting. Since it is possible that the new active drone will start transmitting before the previously active drone has emptied its buffers, there is a risk that packets sent through different TNs may arrive in the wrong order. This issue will be resolved by higher-layer protocols.

Thank you for your attention