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

Poznan Workshop, October 2024

UAV and electronic warfare means on Ukrainian battlefield: state of the art and challenges

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Specialization in aerial reconnaissance with UAVs

Russo-Ukrainian War after 24 February 2022

Full-scale invasion of Ukraine
with the goal of genocide of Ukrainians

“Occupation of Kyiv in 3 days”

Biggest conflict in Europe since WW2
Started 27 February 2014

Russo-Ukrainian War: how it’s going

UAVs in Russo-Ukrainian War since 2014

Civil drones for ground operations support since 2015 year

Volunteering organizations and funds organize operator trainings and UAV supply to battlefield

Modifications of civil drones: NFZ, DJI Airoscope, ATTI mode

Mariia Berlinska with her DJI Phantom drone circa 2017

Main UAV classes and tasks on battlefield

Multirotor UAVs

Reconnaissance (powerful day optics, night vision), artillery correction (video stream over Starlink), assault support, IED delivery, cargo delivery, remote mining, special operations (damaged drone evacuation, kamikaze missions, fire strikes)

DJI Mavic, Autel Evo, big drones (DJI Matrice…), local production

FPV drones

Ground strike drones (with different payloads), anti-aircraft (effective against russian reconnaissance drones)

Assembled locally from Chinese components (costs 350+ USD)

Fixed wing drones

Long-range reconnaissance, kamikaze missions (against russian military factories, oil refinement plants)

Open problems in UAV applications

Electronic warfare

Russia has EW on par with worlds most advanced technologies (EW and land mines are priorities in russian military R&D)

China is unofficial ally of russia, supplies electronic components

Signals intelligence

FPV drones are sensitive to video stream delays, analog signal without encryption is common

Intelligence data analysis

Image and video “decoding” (enemy forces recognition) from aerial reconnaissance data is still done manually, reports are delayed for hours (in some cases 6 hours!)

Electronic warfare capabilities of russia

Characteristics of R-330Zh “Zhytel” signals:

Operating frequency range:

- when conducting radio reconnaissance - 100 ... 2000 MHz;
- when conducting radio suppression - 800 ... 960; 1227.6; 1575.42; 1500 ... 1700 and 1700 ... 1900 MHz.

a) radio suppression of mobile stations of the Inmarsat and Iridium mobile satellite communication systems;

b) radio suppression of base stations of cellular communication systems of the GSM 1900 standard;

c) radio suppression of navigation equipment of users of NAVSTAR satellite communication systems (GPS).

Types of interference signal types:

targeting by frequency, targeting and jamming by frequency, jamming;

- transmitter power - 1000 W

Electronic warfare capabilities of russia

"SHYPOVNYK-AERO" is equipment for combating UAVs, TV and radio broadcasting stations, command communication points, stations (modules) of cellular and other networks. The hardware provides both broad-band and narrow-directional suppression of signals and frequencies, changing the source of radiation transmitting information. In the latter case, the struggle is not with the source of radiation, but with the receiver of information.

Main characteristics:

- radio direction finding frequency range: 25-2500 MHz;
- radio suppression frequency range: 25-100; 400-500; 800-925; 2400-2485 MHz.

Electronic warfare capabilities of russia

RP-377UVM1 «LISOCHOK»

Subranges, MHz - 20-80; 100-130; 120-197, 150-408, 386-1020.
radio obstacle bandwidth, MHz - 60; 30;77;258;634 (accordingly to the frequency subrange)
Source Power - 20;20;20;20;20 (accordingly to the frequency subrange).

Electronic warfare capabilities of russia

LPD-801 anti-drone gun
Subranges, MHz - 2400-2483,5; 5725-5825; 1575- .,
1602- .,
radio obstacle bandwidth, MHz - 83,5; 100
Source Power - 10;5;4;4 – accordingly to the frequency subrange.

Electronic warfare capabilities of russia

The complex of electronic warfare with the "POLE-21" UAV

- suppressed satellite channels - GPS/Galileo/GLONASS/BeiDou;
- range of suppression - not less than 25 km;
- rated output power of the transmitters in the 1st ant. - 80W (amplification coefficient of antenna +/-7dBi);
- consumed power – 600W;
- type of interference - frequency-targeted and phase-manipulative with a pseudo-random sequence.

Electronic warfare capabilities of russia

Automated obstacle station R-330 BMW
- radio reconnaissance in the range of 25 - 960 MHz on fixed radio frequencies;
- suppression of working frequencies with a speed of up to 1000 s/s and a working time at one frequency of at least 1 ms;
- transmission of short telecode messages.

Electronic warfare capabilities of russia

EW complex "Sylok-01" UAV
- suppression range of control and navigation channels - 4000 m;
- width of the directional diagram - 360 degrees; - interference power – up to 50 W;
- operating frequencies - 390-490 MHz; 870-950 MHz; 1200-1300 MHz; 1550-1600 MHz; 2200-2500 MHz; 4900-5900 MHz.

It can be mounted on a vehicle, and the power consumption is 600 W.

Electronic warfare capabilities of russia

Automated radio interference station R-934UM
Detection, analysis, direction finding of sources of radio radiation and creation of obstacles to radio communication lines, cellular and trunking radio communication systems, and television systems.
radio suppression operating frequency range, MHz – 100-400
radio reconnaissance range, MHz – 100-2000
output power of the interference transmitter, W – 1000
the number of suppressed frequencies – 4

Automated radio interference station "Altaiets-AM"
Detection, analysis, direction finding of sources of radio radiation and creation of obstacles to radio communication lines, cellular and trunking radio communication systems, and television systems.

radio suppression operating frequency range – 100-965
radio reconnaissance range – 100-2000
output power of the interference transmitter, W – 200

Electronic warfare capabilities of russia

Mobile automated electronic warfare complex «Leer-2»
Conducting radio reconnaissance, identifying sources of radio radiation and setting radio obstacles. Creating a real jamming environment, simulating the operation of various radio-electronic devices and evaluating the electromagnetic environment.

radio suppression operating frequency range, MHz – 20-2700
output power of the interference transmitter, W – 200-500 (depending on antenna type)

Electronic warfare capabilities of russia

Full-functional complex of radio-control, radio-detection and radio-suppression "Lorandyt"

Quick search, localization detection, radio-suppression of radio connection.

Searching and detection, MHz 20-2000

Direction Detection, MHz – 25-2000

Frequencies ranges for obstacles 137-174, 410-470,100-500

Power of obstacle transmitter, W – 100

Electronic warfare capabilities of russia

Electronic warfare complex RB-341V "Leer-3"

Jamming of the GSM900/GSM1800 cellular subscriber terminals from special aircraft.
radio interference range, MHz – 880-915, 935-960, 1710-1785, 1805-1880.
Operating range, km (base station transmitter power, W) – 3,5(2) (console) - 6(10) (centroplane).

Simulation perspectives

What we can take into account:

- Actual UAV parameters
- Electronic warfare type and it’s impact on certain UAV type
- Transmitter power, probability of revealing
- Topography features of battlefield
- Electronic warfare radius of action

Models

We propose to use 3 types of models:

1) Irregular “cellular” automata + imitation modelling
2) Complex networks, and its optimization
3) Petri nets

Expected results are:

1) Comparing results of the simulation between 1) - 3)
2) Comparing key parameters with real data for model validation

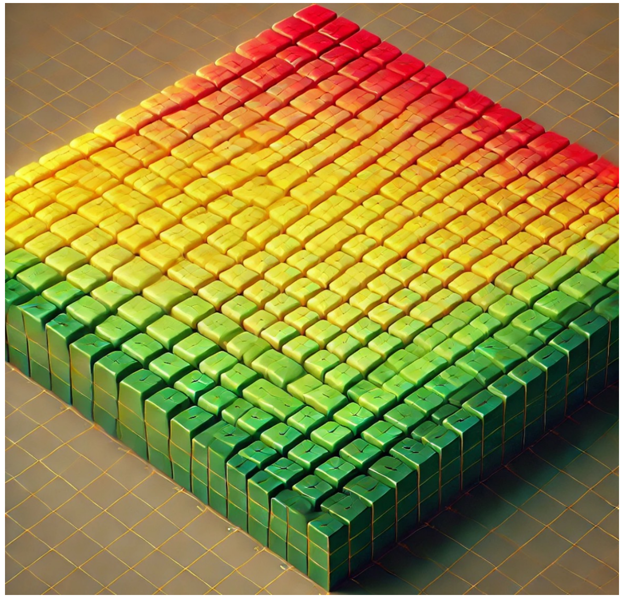
Model Examples. Cellular automata

Automata type: dynamic colored probability automata (black, red, yellow, green), where the state color shows signal level (black means that signal is absent, red – the signal value is critically small, yellow – the signal level is in the middle range, green – the signal level is in maximum range).

The state of one automata cell should be described by following cortege: {S, P}, where S is the signal level, and P is position that consists of {x,y,z} coordinates of UAV.

Neighbours: the maximal number of neighbours is N, where N<>0. For j-th UAV the set of neigbours will be denoted by O_j. The neighbour of i-UAV is j-UAV if I(i,j)=1, where I is an adjacency matrix.

Currently, we've simulated drones movement without signal level changes.



At the figure each cell has 8 neighbours. In general the number of neighbours can be different

Initial conditions

The initial automata state. It is given by an adjacency matrix I, I(i,j)=1 if the connection between UAV i and j exists (non-black level) (and 0 otherwise). I(i,j)=1 if

$$\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2} \leq R$$

where R is a minimal UAV sensitivity distance.

At the every step we reorganize the mesh of UAV's according to their trajectories of movement, so {x,y,z} can change and adjacency matrix should be changed accordingly.

Also the position of *command center* is given: $\{x_c, y_c\}$ (in sense of the model it doesn't differ from ordinary UAV, but has bigger R and stable position).

The positions of *radar warfare devices* are given $\{x_r, y_r, z_r\}$, r=1…M. We consider these devices as such that can decrease signal level. The adjacency matrix for i-UAV and these devices: R(i,r)=1 (rectangle matrix) if

$$\sqrt{(x_i - x_r)^2 + (y_i - y_r)^2 + (z_i - z_r)^2} \leq R_r$$

where R_r is a radar warfare effectiveness distance.

Automata rules

And also we consider radar warfare devices neighbourhood for j-UAV: θ_j.

The automata rules:

1)If $\exists\, i \in O_j : S_i = \{green\}$ then $S_j\{red\ or\ yellow\} \rightarrow S_j\{green\}$ with probability P_g.

2)If $\exists\, i \in \theta_j$ then $S_j\{black\ or\ red\ or\ yellow\ or\ green\} \rightarrow S_j\{black\}$ with probability P_b.

Also there will be

3)additional rules for $\{green\} \rightarrow \{yellow\}$, $\{\text{yellow}\} \rightarrow \{red\}, or\ \{any\ color\} \rightarrow \{black\}$ depending on {x,y,z}, inverse square law and topology characteristics.

Inverse Square Law: Signal strength typically follows an inverse square law, where the signal power decreases with distance.

Signal Strength=Constant/Distance^2

4) additional rule concerning different type radar warfare devices influence for signal level {yellow} $\rightarrow \{red\}$, $\{green\} \rightarrow \{yellow\}$.

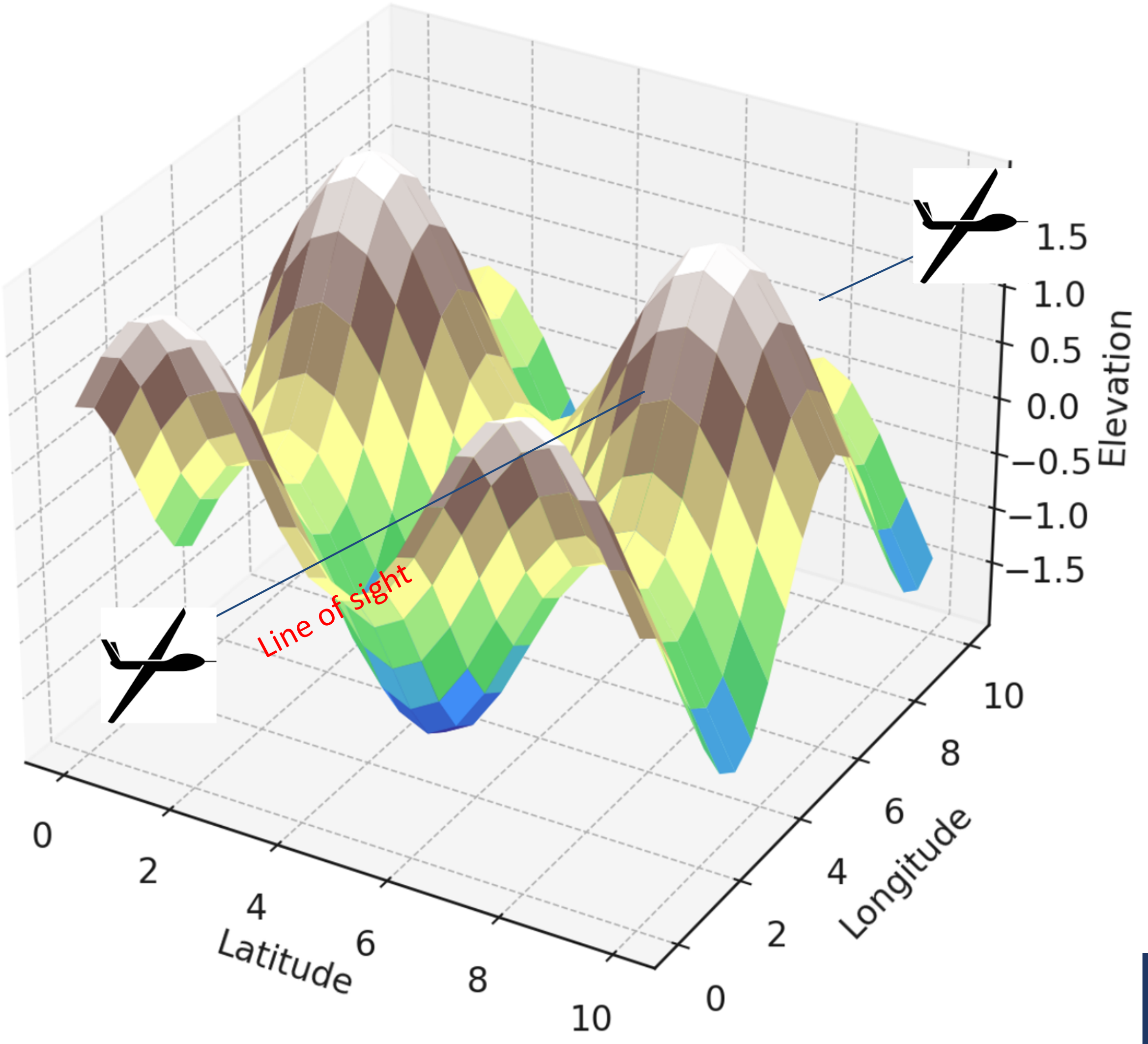
Signal Strength is the strength or intensity of the signal at a certain distance from the source. Constant is a proportionality constant that depends on various factors such as the power of the transmitter, characteristics of the medium through which the signal propagates, and the sensitivity of the receiver. Distance is the distance between the transmitter (source) and the receiver.

Other assumptions

Obstacles and Interference: Signal degradation can also occur due to obstacles such as buildings, terrain features, or other UAVs, as well as interference from other wireless devices operating in the same frequency band. These factors can attenuate the signal and reduce its quality over distance.

Line-of-Sight vs. Non-Line-of-Sight: In scenarios where there is a clear line-of-sight between communicating devices, signal degradation may be lower compared to non-line-of- sight scenarios where signals must traverse obstacles or reflect off surfaces, leading to additional attenuation and multipath effects.

Taking into account topography of battlefield



We plan to use OpenDEM, because Google doesn’t provide high-resolution data about regions under war actions.

The complex network model

The aim of the modelling: We consider the UAV network as a complex network, and should calculate the set of characteristics that can help us to conclude about its stability and additional features.

The shortest path (geodesic line) between any two network nodes is the length of the shortest path between these nodes. When considering an unweighted network, when the conditional weight of each edge is equal to one, the geodesic line is the path from one node to another with the smallest number of steps.

The network diameter is the maximum distance between two network vertices.

The distribution of nodes by the number of connections (**degree distribution**) is a numerical characteristic of a complex network that indicates the probability P(q) that a randomly selected vertex of the network will have degree q. For a directed network, the coefficients for the input and output degrees of the node are calculated separately.

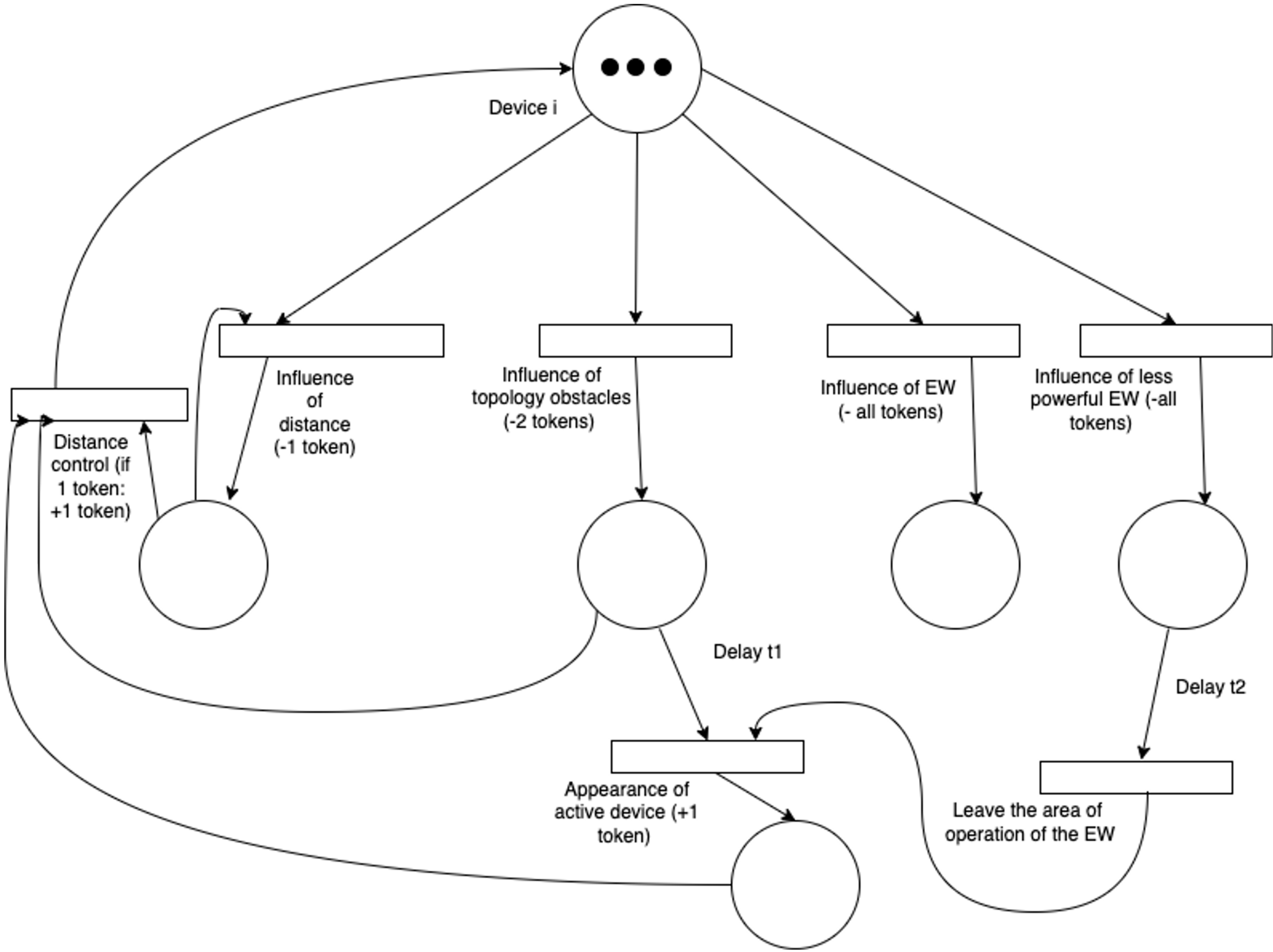
Clustering is a local characteristic of the network that characterizes the degree of interconnectedness of the nearest neighbors of the selected node. Usually, real complex networks have the following property: if any two nodes are adjacent, and one of them is also adjacent to some third node, then the first node will also be adjacent to the last one.

Node load (a measure of centrality, or betweenness centrality) is a coefficient that characterizes the importance of a given node for the network, and is described using the value of the number of shortest paths between some nodes, for which these paths pass through the selected node. This coefficient is described with the help of quantitative calculations of the shortest paths in the network associated with the chosen one.

Petri nets

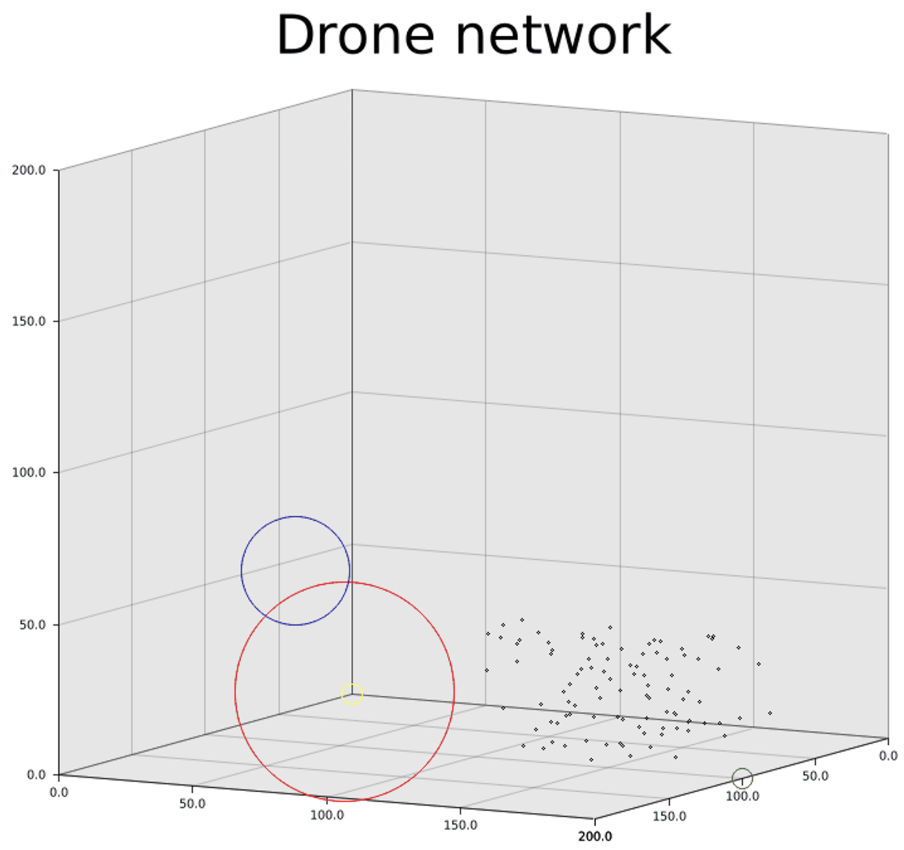
The aim of modelling: to investigate delays of harmful signals distributions, and get another mathematical view on UAV distribution depending on obstacles.

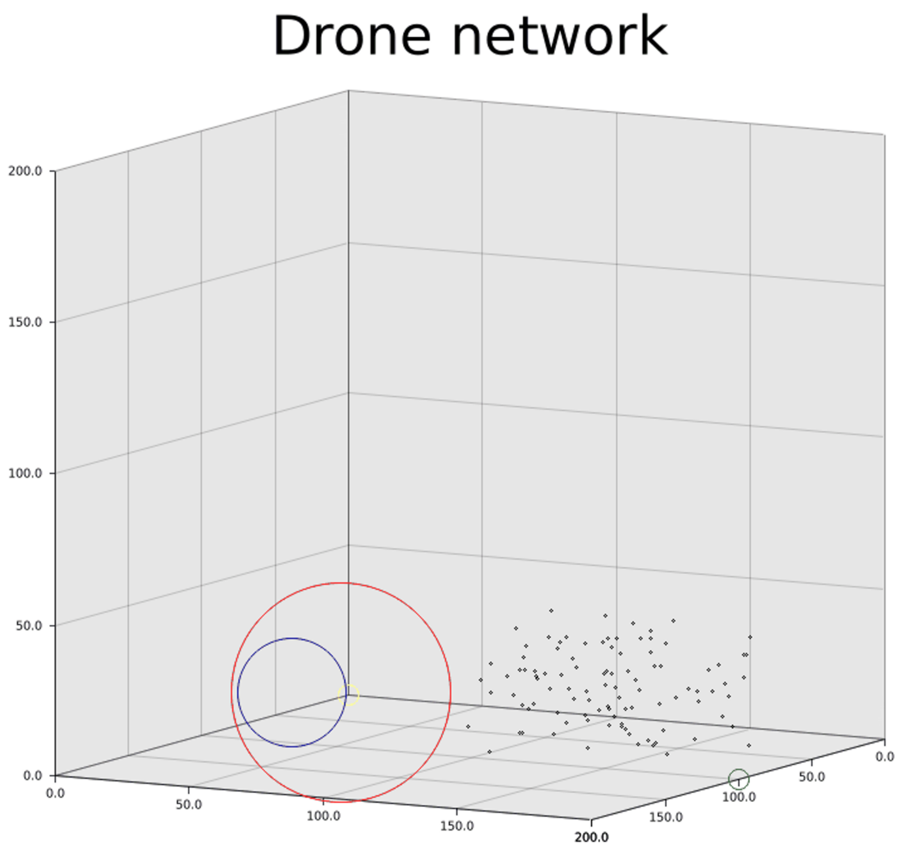
Tokens mark current signal power for certain UAV.



Possibilities for battlefield needs

Prognostic functions - UAV Network optimization - UAV correction





* Black dots - drones.
* Green circle - operating area of the control center.
* Yellow circle is the drone destination area.
 (assume that the drone exploded upon contact with the target)
* The red circle - zone of EW that suppresses the connection.
 When crossing it, the drone no longer receives data about its geolocation and moves horizontally in the same horizontal direction in which it moved before entering the zone.
* Blue circle - zone of action of the EW, which suppresses the control connection.
 When crossing it, the connection with the drone is lost, that is, the drone is removed from the network.

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Reviewed literature and information sources

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Wild Sky school materials

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