



Utilizing 5G theatre network for a mixed reality training solution

Version May 2023

Introduction

- NATO is investigating the use of 5G to support emerging and disruptive technologies (EDTs).
- Two initial use cases were selected for experimentation in 2022:
 - VR training for satellite communications (SATCOM) technicians
 - AR maintenance for SATCOM equipment
- These technologies were deemed of interest for the assessment of 5G networks because they require fast and responsive data transfer.
- The results of the experimentation will be used to inform NATO's future use of 5G for EDTs.

Experiment

- Allied Command Transformation (ACT), with a cross-functional team from
 - Joint Force Development (Experimentation & Wargaming branch (EWB) and Modelling & Simulation Learning Technology branch (MSLT)) and the
 - Capabilities Division (CIS branch), supported by
 - NATO Communications-Information Agency (NCIA) and the
 - NATO Support and Procurement Agency (NSPA) executed an experiment in November 2022.
- This experiment focused on Education and Training of SATCOM technicians and how 5G, VR and AR could optimise their training and the maintenance of their acquired competences.



XR Training Solution for SATCOM Technicians



LEARN

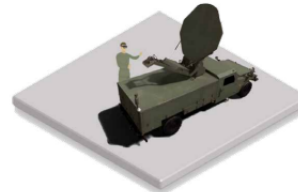
VR SUPPORTED
SELF-PACED



Undergo initial familiarization of the TSGT.

PRACTICE

VR SUPPORTED
INSTRUCTOR-LED



Practice with the basic operational activities.

TRAIN

AR SUPPORTED
INSTRUCTOR-LED



Train on operational and maintenance procedures, both as individuals and in teams.

PERFORM

AR SUPPORTED
SELF-PACED



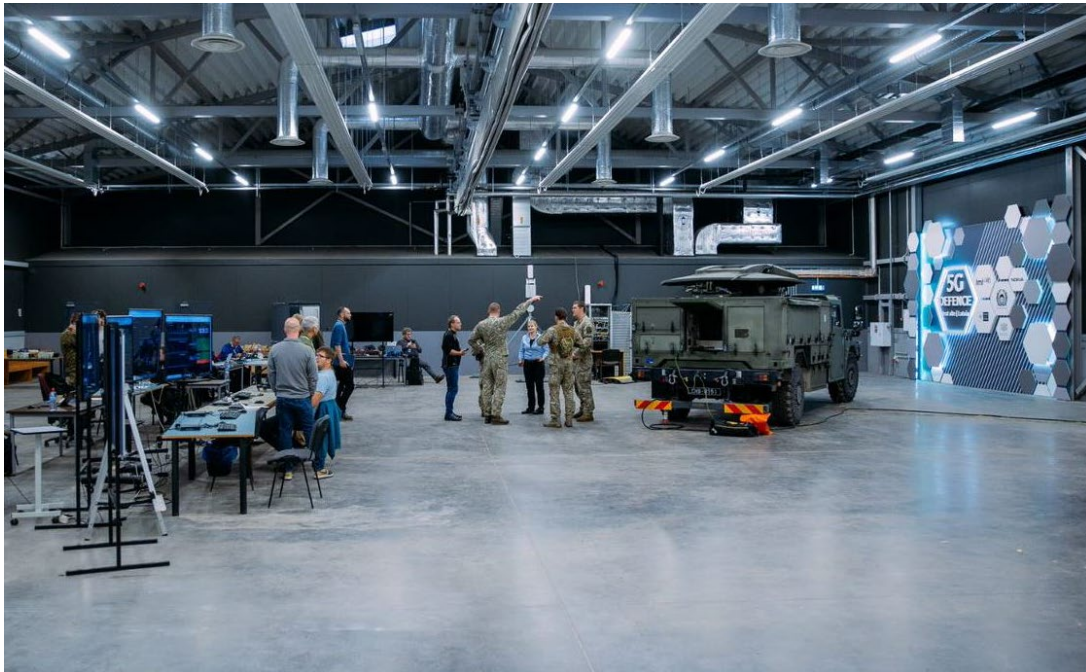
Get support on operational activities via a graphical overlay and/or human instructor that connects remotely.

Experiment Goals



- The goals of the experiment were to:
 1. Assess the viability of different 5G and WiFi networks in support of VR SATCOM training and AR SATCOM maintenance.
 2. Assess the viability of different VR software configurations in delivery of VR SATCOM Training.
 3. Assess the viability of different AR hardware in delivery of SATCOM maintenance and continuous training.

Experiment Methodology



- The experiment was conducted in three phases:
 - Phase 1: VR SATCOM Training
 - Phase 2: AR SATCOM Maintenance (indoor)
 - Phase 3: AR SATCOM Maintenance (outdoor)
- For each phase, all networks were tested against the software configurations (for VR phase) or the hardware devices (for AR phases).
- Technical data based on pre-defined Key Performance Indicators (KPIs) were collected along with end users experience data collection done via data collection forms.

Data Collection



- Technical data were collected on each trial:
 - By Fynd Reality for the data related to the software configuration;
 - By LMT for the data related to network performance.
- End user data were collected via:
 - Self-assessment forms provided to players;
 - Observation forms filled by the analysts with regard to the software configuration rendering.

Phase 1: VR SATCOM Training



- This phase was designed to provide inputs for objective 1 and 2 of the experiment.
 - All trials were played indoors by untrained soldiers.
 - The phase started with a familiarization of all the players with the VR goggles in order to minimize improper use.
 - Each trial was ended either when all assigned scenario steps were completed or after ten minutes, whichever occurred first.

VR Training Experiment Matrix

	WiFi		5G (n79)		5G (3.5Ghz)		5G (mmWave)	
		Tech data	End user assesment		Tech data	End user assesment		Tech data
Software configuration 1	scenario 1A	Team V1 Trial 1.1	scenario 1B	Team V1 Trial 1.6	scenario 2A	Team V1 Trial 1.7	scenario 2B	Team V1 Trial 1.12
Software configuration 2	scenario 1B	Team V2 Trial 1.2	scenario 2B	Team V2 Trial 1.5	Scenario 3A	Team V2 Trial 1.8	scenario 3B	Team V2 Trial 1.11
Software configuration 3	scenario 3A	Team V3 Trial 1.3	scenario 3B	Team V3 Trial 1.4	scenario 1A	Team V3 Trial 1.9	scenario 1B	Team V3 Trial 1.10

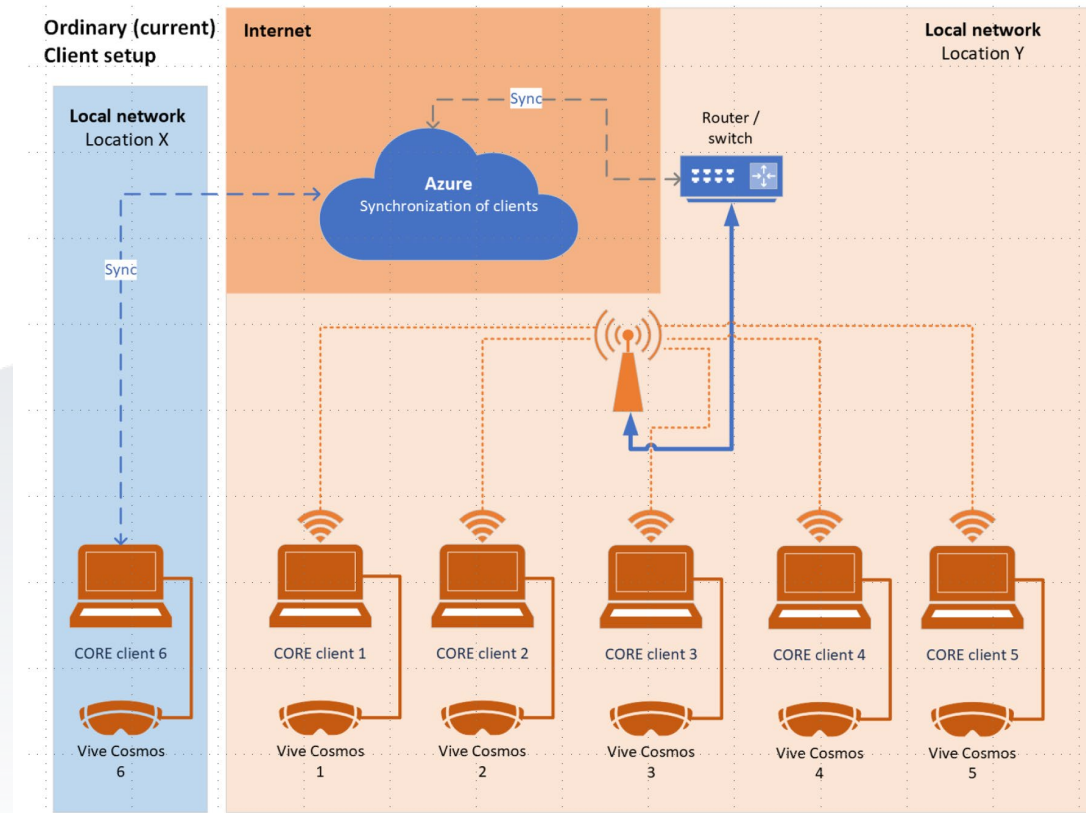
Figure 1. VR training phase matrix of trials

- The scenarios used for this phase of the experiment were derived from the three main modules of the SATCOM Training developed by Fynd Reality: Transportable Satellite Ground Terminal (TSGT) Container Deployment, TSGT Grounding & Lightning protection and TSGT Power-up.

Software configuration 1

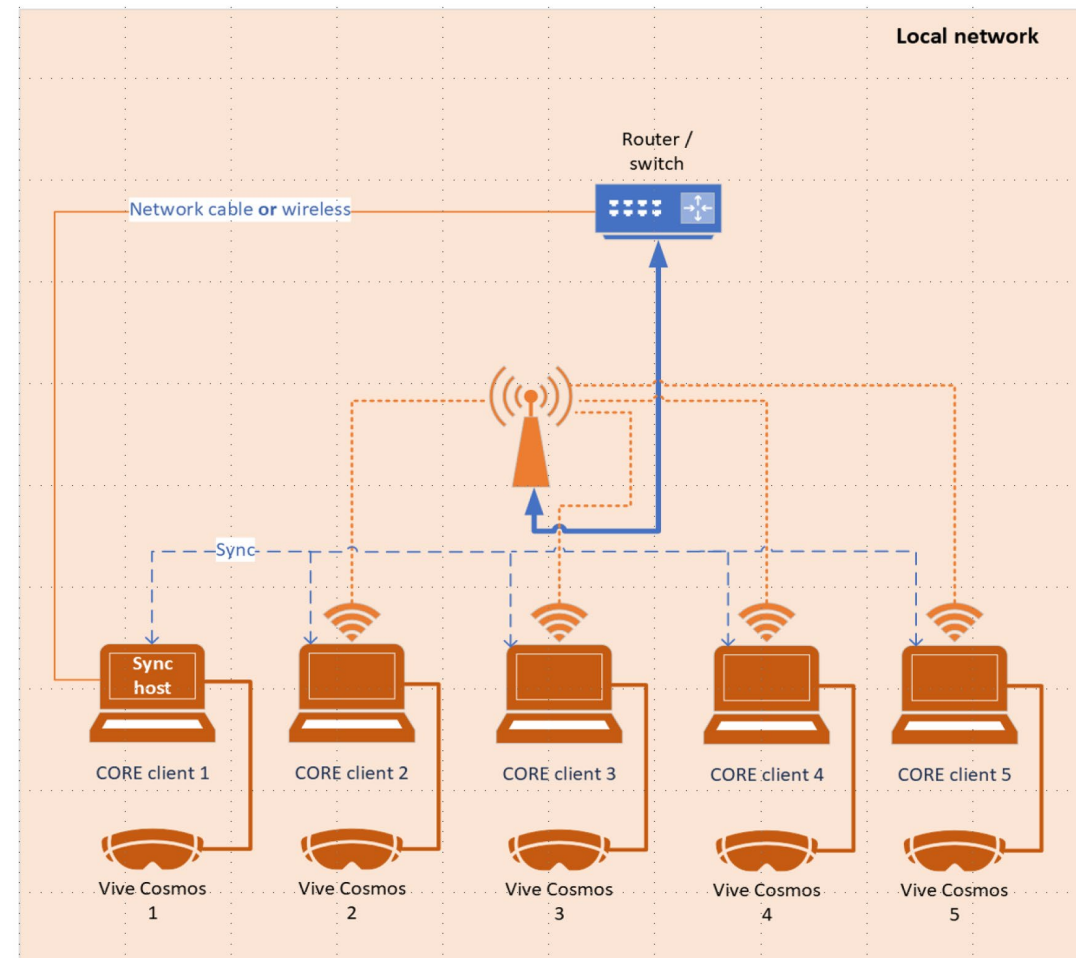
Current (over open internet)

- The Fynd Reality software was downloaded to the client laptop and run as a local application.
- It communicated with the multiplayer server that was located in Azure cloud over the Internet.
- The multiplayer server synchronized the clients and made all the clients see the same actions at the same time.



Software configuration 2 – Local Adazi network (over local network and via VPN)

- The Fynd Reality software was downloaded to the client laptop and run as a local application. The software communicated over a local network with the multiplayer server in the application, running on one of the laptops.
- The synchronization of the clients was in this case done from the server-laptop, and not from the cloud (Azure).



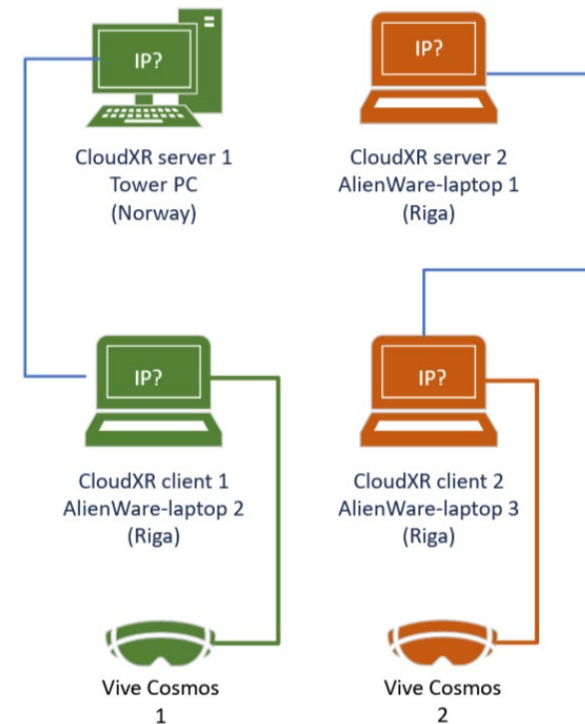


Software configuration 3

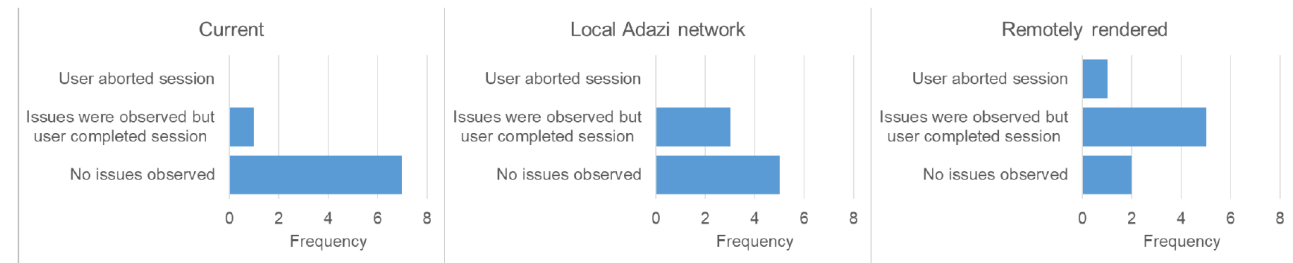
Remote rendered

- The Fynd Reality software ran on a server, and the VR-content was directly streamed from the server to the client as video. This was done in two different setups: the first streaming from a server in Norway, and the second streaming from a server at the Adazi base. Only positioning and controller input data was sent back from the remote rendering clients to the servers.
- There are many steps required to stream each individual image frame through remote rendering of VR:
 - 1. Client: Get input data from input devices
 - 2. Client: Send the input data to the server
 - 3. Server: Run the game logic
 - 4. Server: Render the virtual world individually per eye
 - 5. Server: Encode the resulting images
 - 6. Server: Send the encoded images to the client
 - 7. Client: Decode the images
 - 8. Client: Display the images in the HMD (device)
- This demonstrates why remote rendering is resource heavy. To ensure the user experience is adequate, the time from input to perceived effect on the screen must be as low as possible.

**TSGT - Offline version
(Remote Rendering session)**

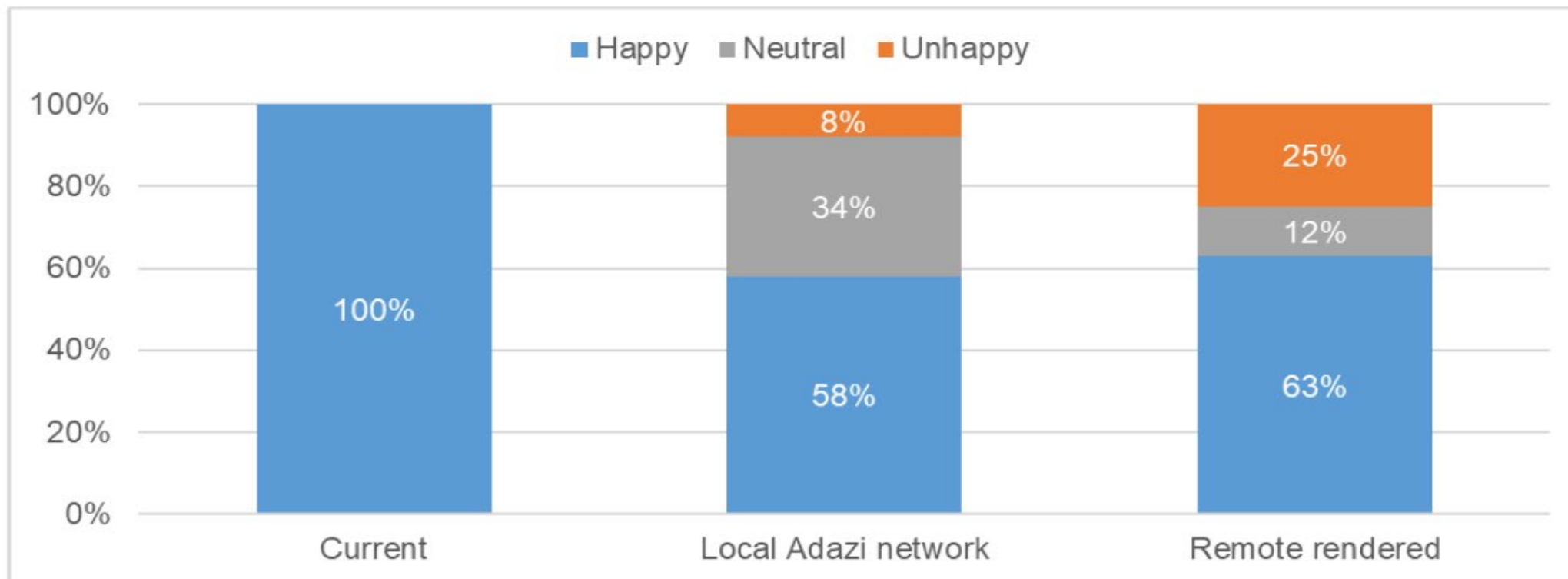


Frequency of observed issues for each software configuration

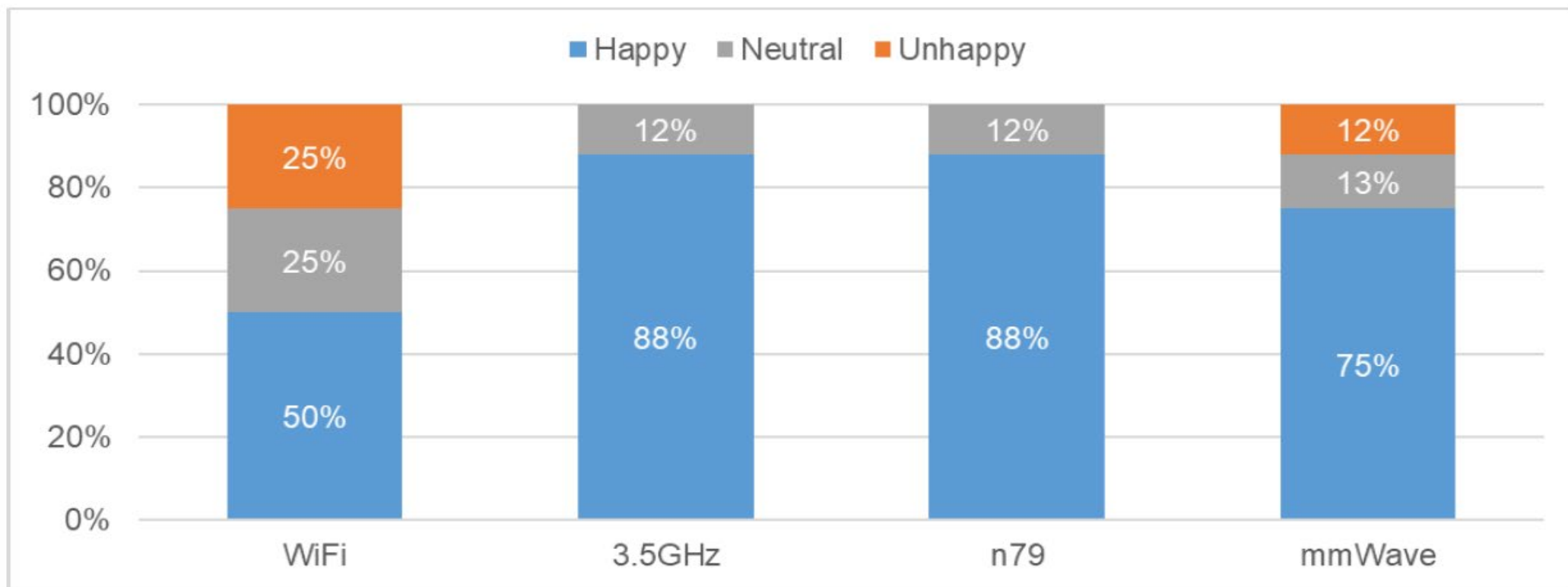




Participant satisfaction of overall experience by software configuration



Participant satisfaction of overall experience by network configuration



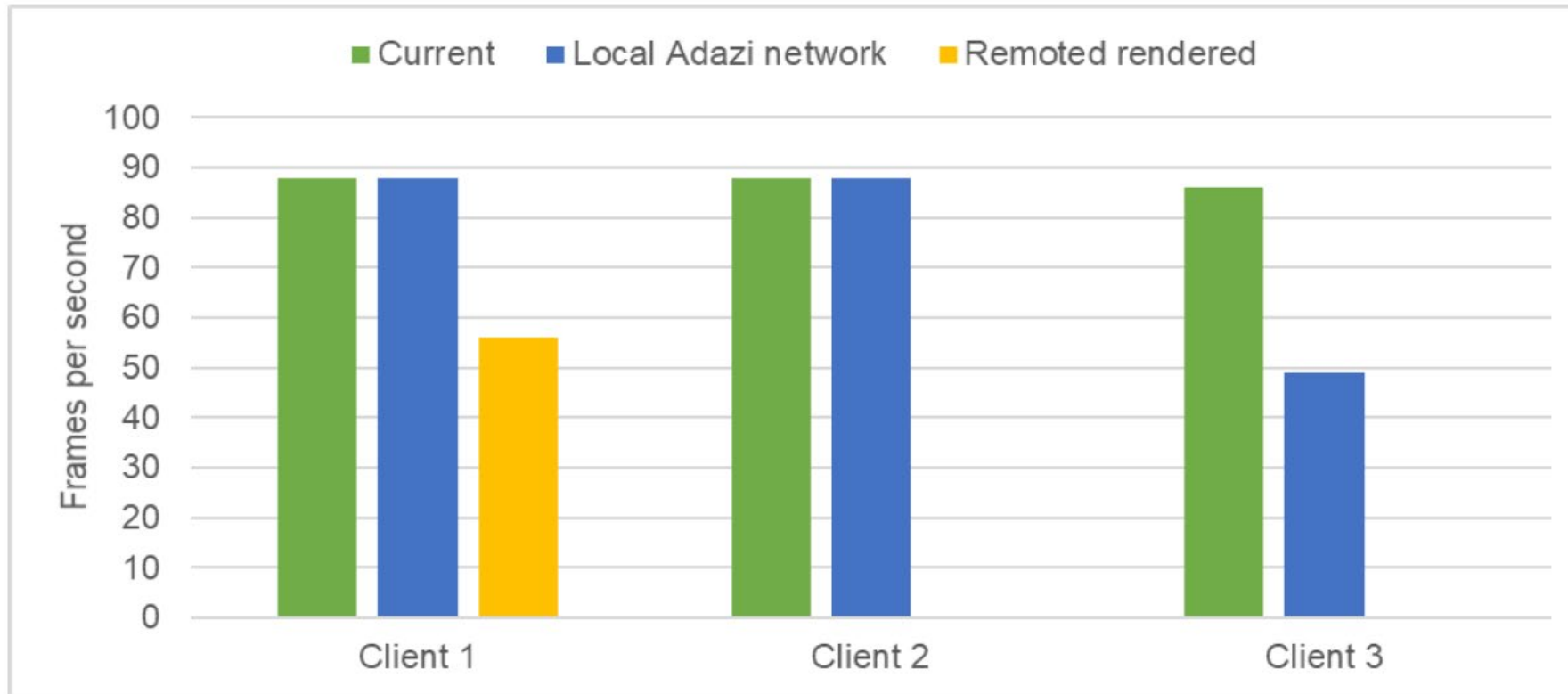
Average performance of each software configuration



Software configuration	Download (Average Mbps for one user)	Upload (Average Mbps for one user)	Ping (ms)
Current, Local Adazi network	3	3	100
Remote rendered	85	85	50



Average frames per second by software configuration



Average frames per second by network configuration



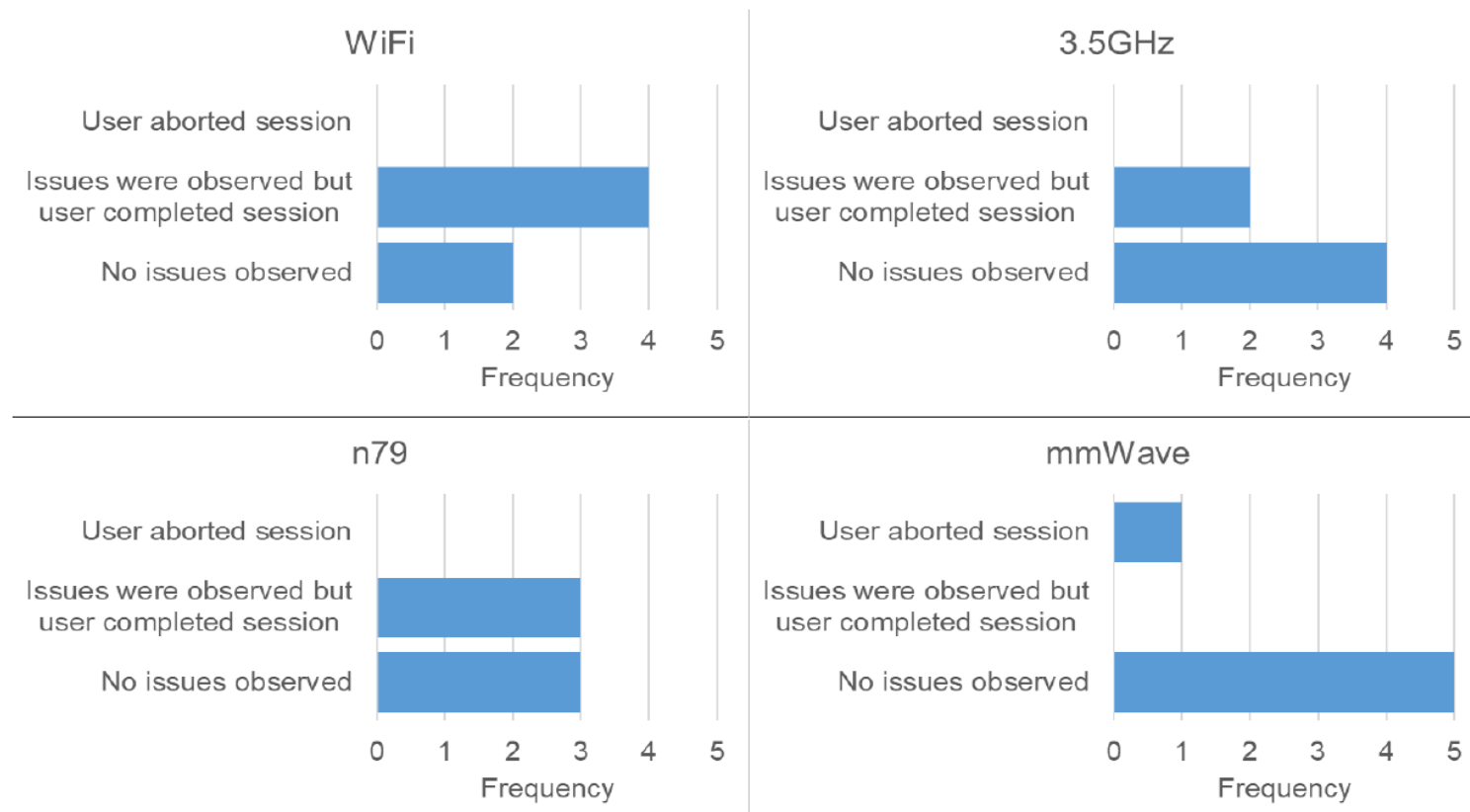
The four network configurations tested were:



1. WiFi: Standard WiFi6 (5GHz) connection;
2. 5G NSA 3.5GHz (Public network) –Most popular global 5G setup. Will likely remain the most popular for at least the next few years;
3. 5G Non-Stand Alone (NSA) mmWave (Public network) – Configuration was chosen due to its high data speeds. mmWave is only working with 5G NSA for now;
4. 5G Stand-Alone (SA) n79 (Private network) – Future private network configuration which is seen as the most promising option for military use-cases. The experiment used two vendor 5G SA networks (Ericsson for VR and Nokia for AR) and the n79 (4.5-5GHz) frequency which is owned by NATO.



Frequency of observed issues for each network configuration



Phase 2: AR SATCOM Maintenance (Outdoor)



- This phase was designed to provide inputs for objective 1 and 3 of the experiment.
- All trials were played outdoors by trained TSGT Technicians.
- The phase was designed to reflect a close to reality environment.
- SATCOM maintenance experts from the Combat Service Support Company (CSSC) UltiSat site in NLD were connected to provide remote support.
- However, technical issues forced to redesign this phase on the spot in order to fit all the trials in a reduced timeframe.
- The TSGT truck on which maintenance was to be executed was parked at approximately 145 meters from the actual network antenna.
- The area had scattered trees, the weather was cloudy with a temperature between eight and eleven degrees Celsius.
- Each trial was concluded when all assigned scenario steps were completed or after ten minutes, whichever occurred first.



AR Maintenance Outdoor Experiment Matrix

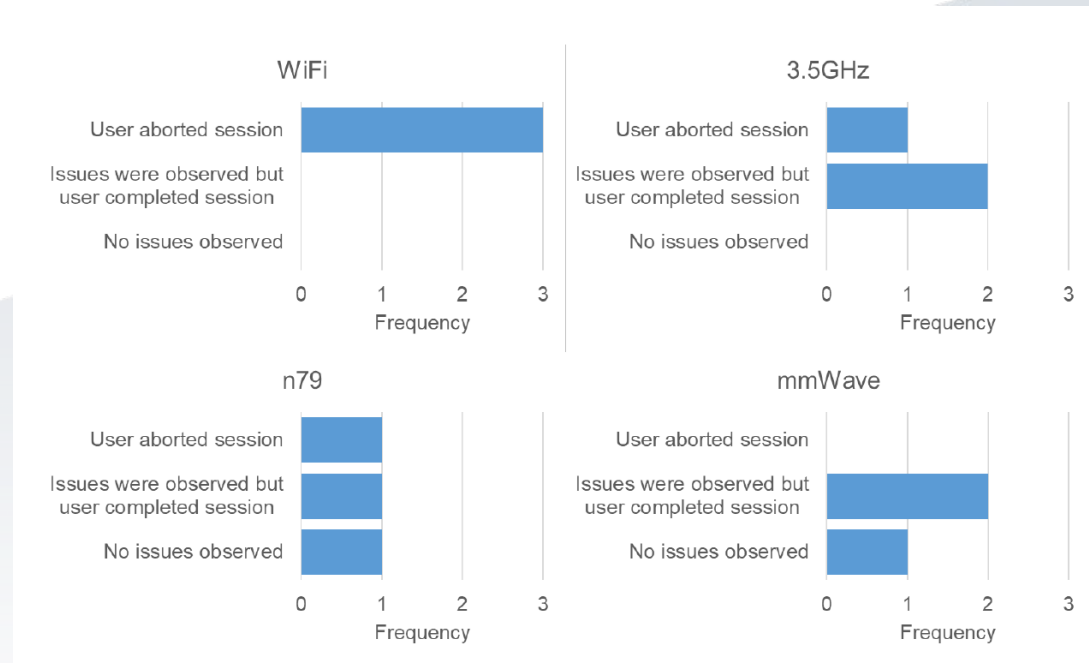
outside	5G (3.5Ghz)		5G (mmWave)		5G (n79)		WiFi5	
		Tech data	End user assesment		Tech data	End user assesment		Tech data
AR on hololens	Trial 2.1	Team A1	Trial 2.4	Team A2	Trial 2.7	Team A1	Trial 2.10	Team A2
AR on tablet	Trial 2.2	Team A2	Trial 2.5	Team A1	Trial 2.8	Team A2	Trial 2.11	Team A1
AR on phone	Trial 2.3	Team A1	Trail 2.6	Team A2	Trail 2.9	Team A1	Trail 2.12	Team A2

The matrix of trial and scenario steps were kept as initially planned.

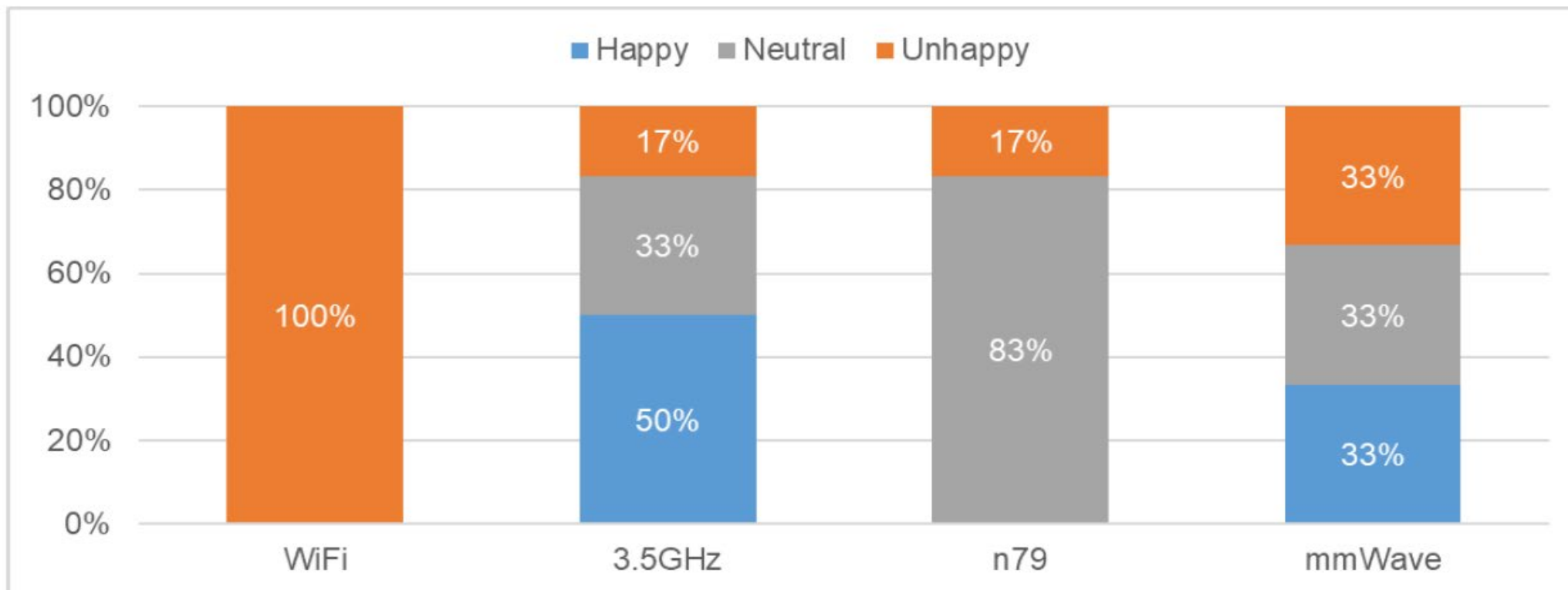
However, team A1 and A2, initially composed of two TSGT Technicians each, were in reality played by two Fynd Reality experts (allowing them to overcome the technical difficulty of rapidly resetting the software at each loss of network connection and moving quickly through a known scenario) and without actually interacting physically with the truck (faster approach also corresponding to ability to interact with the truck).

The re-design allowed execution of all the trials as planned, however it had an impact on the results and comparability of the data collected.

Frequency of observed issues for each network configuration



Participant satisfaction of overall experience by network configuration



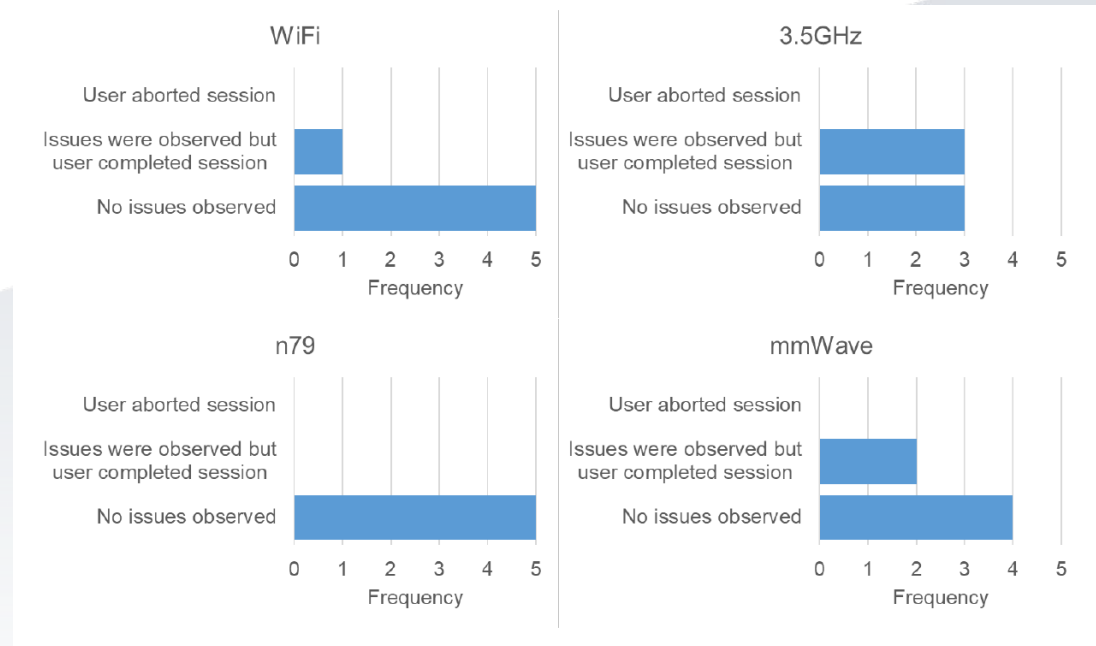


Phase 3 – AR maintenance - Indoor

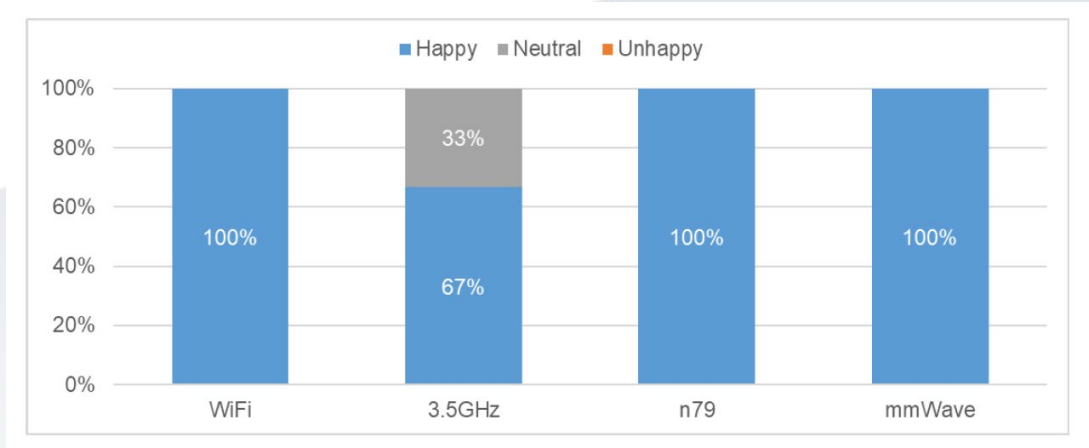


- This phase was designed to provide inputs for objective 1 and 3 of the experiment.
- It was played indoors by trained TSGT Technicians.
- The phase was not designed to assess the actual AR Maintenance software itself, but to capture data on actual network and hardware comparison.
- SATCOM maintenance experts from the Combat Service Support Company (CSSC) UltiSat site in NLD were connected to provide remote support.
- The TSGT truck was parked inside the hangar providing the 5G testbed.
- Each trial was concluded when all assigned scenario steps were completed or after ten minutes, whichever occurred first.

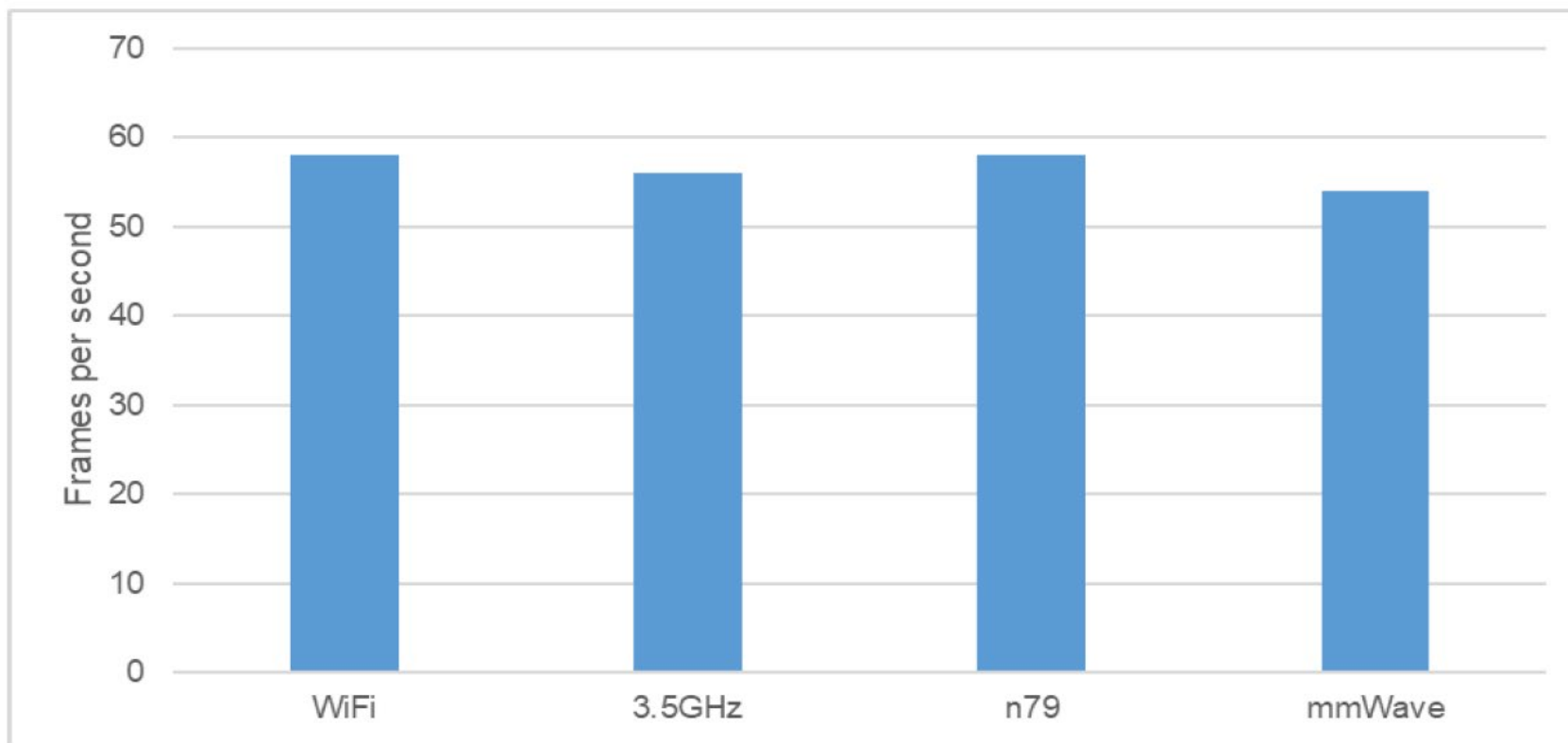
Frequency of observed issues for each network configuration



Participant satisfaction of overall experience by software configuration



Average HoloLens frames per second by network configuration



Minimum signal strength (dB) – average of three sessions – for each 5G network configuration (AR, indoor and outdoor)

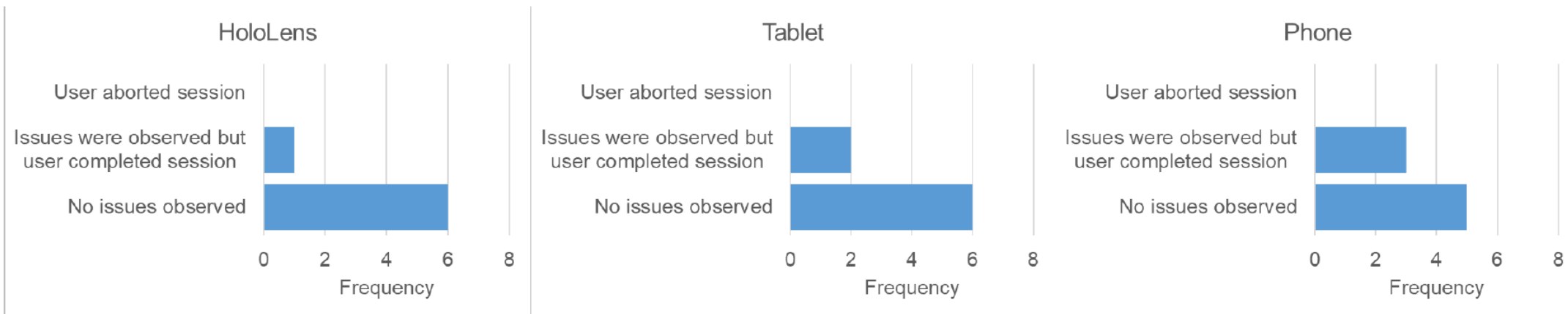


Hardware Configuration in support of AR SATCOM maintenance

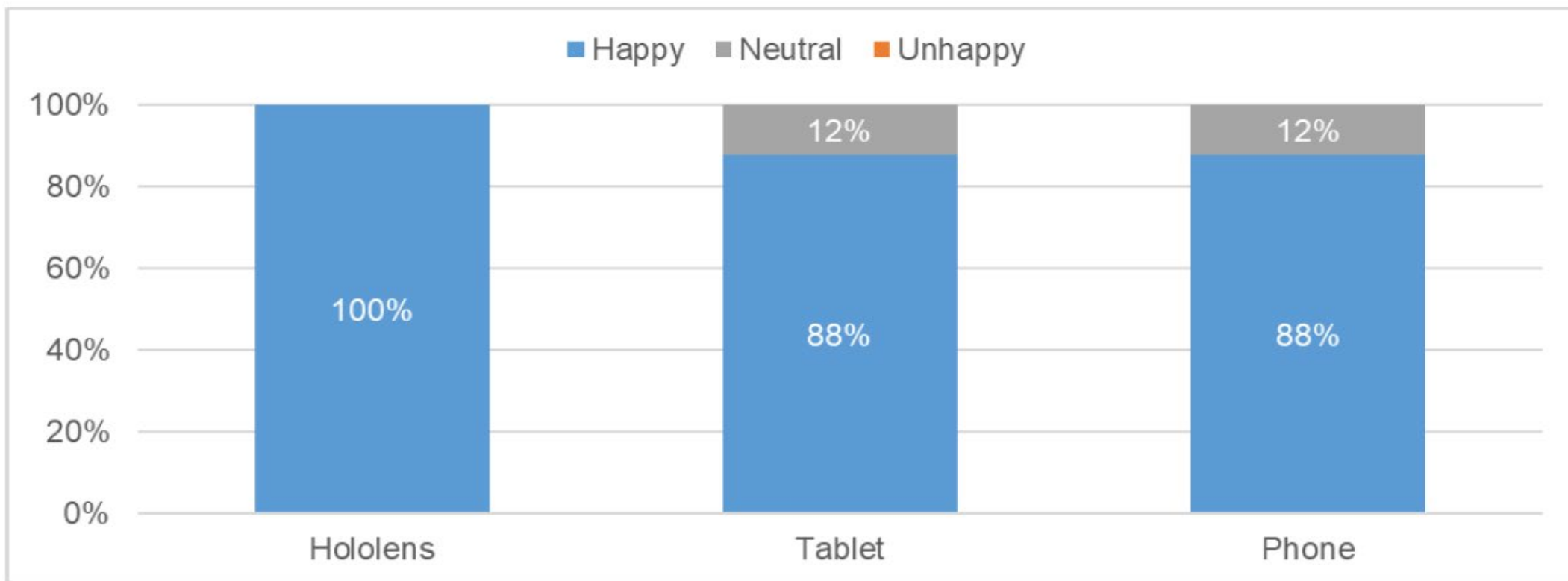


- Three different hardware configurations were tested over the two days, these were:
 - HoloLens – Microsoft HoloLens 2
 - Tablet – Samsung Galaxy Tab S7
 - Phone – Samsung S21 5G

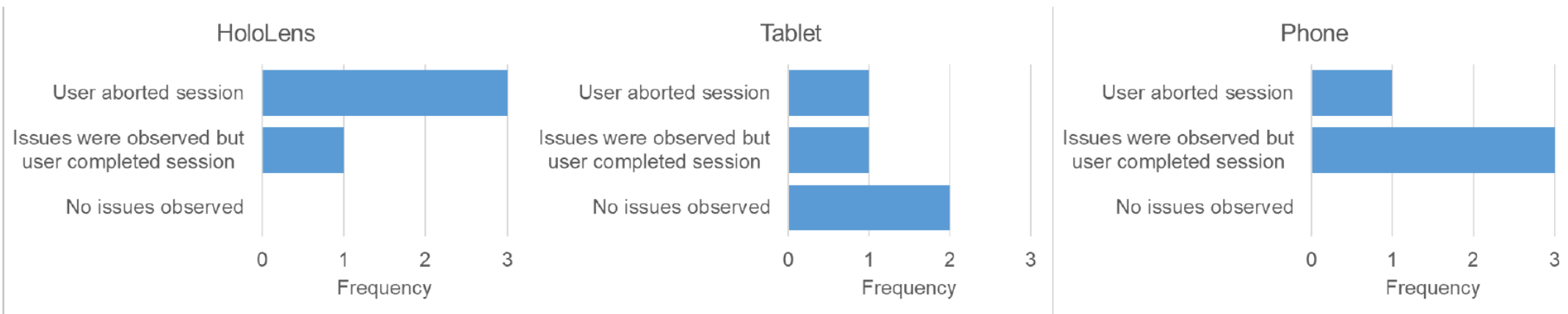
Frequency of observed issues for each software configuration (AR Indoor)



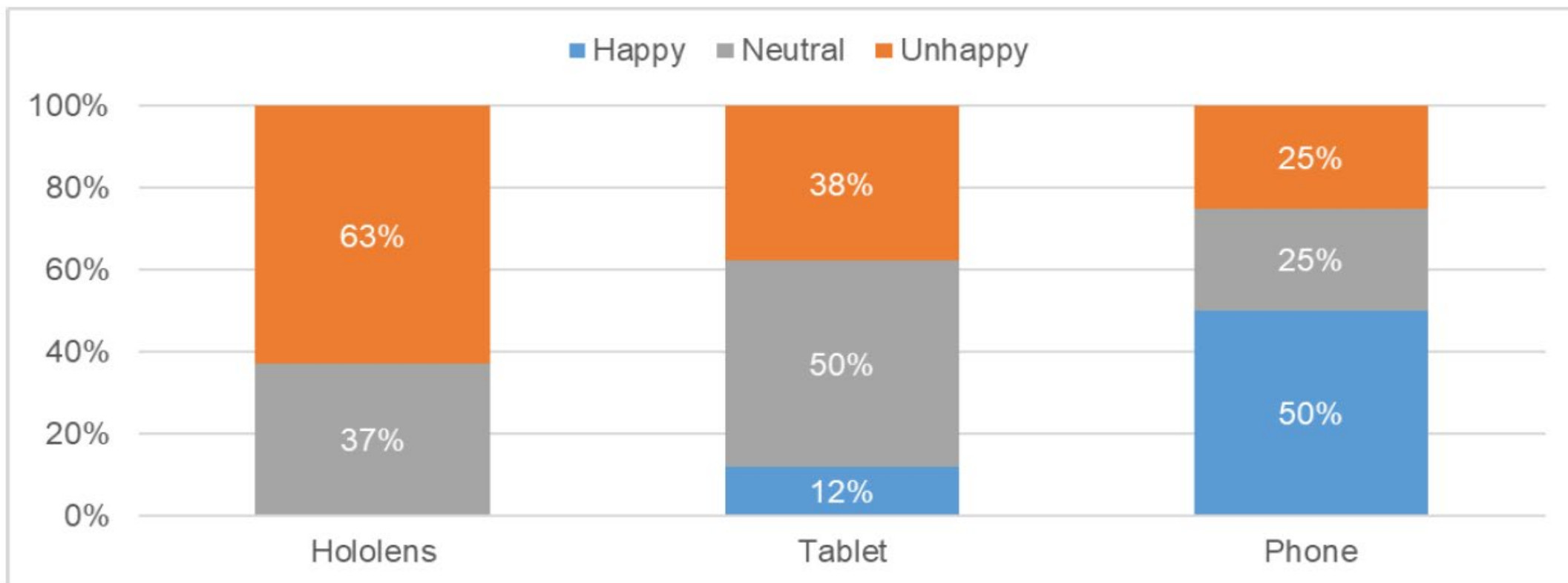
Participant satisfaction of overall experience by hardware configuration (AR, indoor)



Frequency of observed issues for each software configuration (AR, outdoor)



Participant satisfaction of overall experience by hardware configuration (AR, outdoor)



Key Takeaways from the Experiment



Software Configuration

- The VR SATCOM current configuration performed the best, with the least observed issues and had the most positive participant feedback.
- The VR SATCOM local Adazi network configuration performed slightly worse, suffering from a myriad of audio-related issues.
- The VR SATCOM remote rendered configuration suffered from issues relating to the rendering of the guides and recording of step completion, with latency issues noted by the analysts for half the sessions.



Network Configuration

- The use of 5G infrastructure to support both VR training and AR maintenance in an indoor controlled environment was a success.
- There were significant connection issues experienced across all tests during the outdoor AR session.
- Further work needs to be done to understand the limitations of these technologies when employed in an external, “real world” setting, and in particular when used to support deployed maintenance of equipment.



Hardware Configuration

- The HoloLens was identified as the soldier's favourite solution for AR SATCOM maintenance, however there appeared to be consensus that each solution had its own pros and cons.
- To be a viable option, a ruggedized HoloLens solution is required that is less sensitive to both bright and low light (the former leading to the cameras getting saturated, and the latter making surface recognition difficult). It must also be able to operate across a range of weather conditions.
- A phone provides a simple low cost solution in comparison, and appeared to be generally preferred over the use of the tablet due to its more portable form factor.
- While ergonomics were a clear discriminator between the three pieces of hardware, the lighting conditions appeared to be a reoccurring issue for all three.

Experiment Results

- All 5G networks were able to support VR SATCOM training and AR SATCOM maintenance.
- The local client VR software configuration performed the best for VR SATCOM training.
- The HoloLens was the preferred AR hardware for SATCOM maintenance.



Experiment Conclusions for NATO

- 5G, VR, and AR are viable technologies for supporting SATCOM training and maintenance.
- Further research is needed to understand the performance of these technologies in more challenging environments.

Recommendations

- Further research is needed to understand the performance of these technologies in more challenging environments.
- NATO should continue to invest in 5G, VR, and AR technologies.
- NATO should develop training and maintenance plans that leverage these technologies.

Contact

Email andreas.kerl@act.nato.int

Extension 4112