Full-Duplex Radio Technology for Enhanced Defence Capabilities Against Drone Swarms

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0.1 Full-Duplex Radio Technology

To date, most radio technology (civilian, military, drone, counter-drone, etc.) are of half-duplex (HD) type, meaning that simultaneous transmission and reception on the same frequency is impossible. That is because, when a radio is transmitting a signal, that signal inevitably reaches the receiver of the same radio, causing self-interference (SI) that drowns out any signals-of-interest. Up until recently, this limitation had been considered too ambitious to overcome so that, in order to hide this limitation from the user, either frequency-division duplex (FDD) or time-division duplex (TDD) operation is used in almost every wireless application. That means either using different frequencies or time slots for transmission and reception. The principal difference in full-duplex (FD) radios compared to conventional HD radios is the addition of SI cancellation methods to suppress the transmitted signal that inevitably leaks into the receiver path. This prevents the powerful SI from submerging the typically weak received signal-of-interest. Recent academic FD radio prototypes achieve SI cancellation in excess of 100 dB, which provides reasonable communication conditions in non-military wireless applications [1]. The most obvious advantage is that FD radios **double the capacity in a point-to-point communication** — a significant advantage over FDD and TDD operation modes. This can, for example, save mobile operators millions of euros in costs for frequency licenses by effectively allowing the operators to provide the same level of service with half the frequency bandwidth.

In the defence domain, the consequences of true FD radio technology can be even more influential resulting in a wireless superpower. Especially it is so as FDD and TDD are not optimal for many electronic warfare (EW) tasks, such as detection and neutralisation [2]. The former, FDD, is almost never considered for combining detection and neutralisation because only one of two outcomes can arise — detection without neutralisation or neutralisation without detection, neither of which is desirable. The option which is typically turned to, TDD, forces a trade-off between situational awareness and neutralisation efficiency. By dividing detection and neutralisation operations in time, situational awareness and neutralisation efficiency depend on the portion of time spent in either state. But here the FD radio technology excels — it removes that trade-off and opens the way for combining different EW tasks on the same frequency simultaneously. And not only different EW tasks but EW tasks can be combined with tactical communications. Thus, FD radio technology is a **key enabling technology to develop multifunction military radios**, which have long been coveted by defence forces [3]. In other words, FD radio technology allows to integrate EW, tactical communications, and signals intelligence into a single device.

Neutralising enemy wireless communications is very often approached in an all or nothing kind of way through barrage jamming. The principle of barrage jamming is to cover the whole frequency band that the enemy might use with a jamming signal. On one hand, this is a robust approach given the limitations of modern radio technology but on the other hand, this requires a lot of power to cover large frequency ranges and this kind of approach damages all radio frequency (RF) communications within these frequency ranges, including friendly communications. However, we can make sure that **collateral damage is minimised** with FD radio technology by directing jamming energy on demand to target only the RF communications used by the enemy (e.g., malicious drones). That is only possible because FD technology allows to analyse the effectiveness of jamming, and to see if the communications or other RF-based systems like radars, which are being jammed, change their operation. Consequently, the jamming can be adapted to be more effective and focus only on the malicious RF systems. Not only would FD radio technology give an advantage to defensive technologies, it would also benefit attack-minded applications, which itself is motivation for either side to not miss out on this radio superpower.

0.2 Full-Duplex Radio Technology Against Drone Swarms

We propose to apply the FD radio technology for counter-drone purposes in the form of a FD radio shield. In same-frequency simultaneous transmit and receive (SF-STAR) operation mode, a FD node can simultaneously interfere with the various RF communication links and RF systems used by a drone swarm and itself receive those signals uninterrupted. The interference creates an invisible electromagnetic (EM) shield, so called FD radio shield, around the FD node as illustrated in Fig. 1. Interfering could in this case mean both jamming (i.e., simple denial of service to the EM spectrum) or spoofing (i.e., taking over a drone if more knowledge about the targeted drone is available). The concept of FD radio shield has already been shown feasible in a laboratory environment, e.g., disabling drone remote control (RC) links by jamming while simultaneously receiving communications [4] or simultaneously detecting the RC links [5] have been reported.

A ground-based FD radio shield (either mobile or stationary) allows to prevent

(swarming) drones from communicating within the swarm while at the same time monitoring the swarms' attempts to communicate within itself — this allows to simultaneously prevent the swarm (even an autonomous swarm) from operating as a coherent unit (communications within the swarm are essential for the functioning of the swarm) and to track the drones by their RF fingerprints (classify and locate individual drones);

(controlling) ground control station from directing the drone swarm while at the same time intercepting the command and control signals — this means that within the radio shield, the swarm is completely cut off from its ground control station but the FD node can still observe (classify and locate) the ground control station;

(navigating) drones inside the swarm from determining their geographical position using global navigation satellite systems (GNSSs) while at the same time retaining the FD node's own access to GNSS — the swarm can not determine its position using GNSS but the FD node can, which is essential in case of a mobile FD node;

(positioning) drones from positioning each other inside the swarm using RF-based methods (two-way ranging or radar-based positioning) while at the same time detecting those efforts — the ability to position each other within the swarm is essential for the operation of a swarm and without this, the swarm becomes paralyzed, yet with FD capabilities those positioning attempts can still be detected.

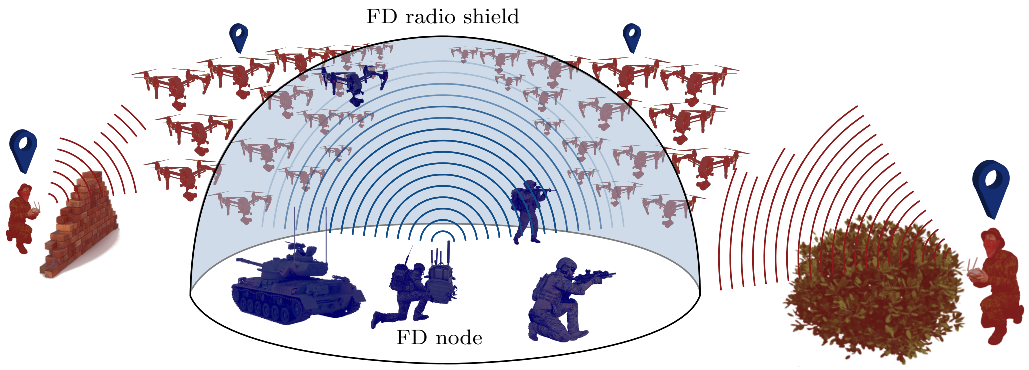

Figure 1: Full-duplex (FD) radio shield against a swarm of drones — simultaneously restricting unauthorized drones access to the defended airspace and monitoring the radio-frequency (RF) spectrum (detection, classification, and localisation of drones and their ground control stations).

On the other hand, a ground-based FD radio shield (either mobile or stationary) also facilitates

(integrating) locating drones while simultaneously jamming their RC links and other RF systems by using joint radar and jamming waveforms — FD radio technology can become a key enabler for multifunction military radios and RF convergence that have for long been coveted by armed forces [3];

(operating) controlling an allied drone (or drone swarm) from the ground station while at the same time simultaneously sensing for enemy drone's RC signals and electronic attacks (EAs) within the same frequency band that is used for allied drone RC.

The last item conveniently introduces another, more proactive, option to use FD radio technology for countering drone swarms as illustrated in Fig. 2. Instead of using a stationary or mobile ground-based FD radio shield, a drone itself could be mounted with FD capabilities. A drone with FD radio technology would allow to

(disrupting) interfere with the entire RF spectrum (ground control, inter-drone communications, two-way-ranging, radar, etc.) used by a malicious swarm, while itself retaining the ability to communicate with its ground control station — when the friendly drone operates on the same frequency as the adversarial drones, FD technology is needed so that the friendly drone can transmit interference and receive commands at the same time;

(spoofing) transmit spoofed GNSS signals while itself receiving the actual GNSS signals — this could be used to direct the malicious swarm away from its target through GNSS spoofing, although successful GNSS spoofing itself can be expected to be highly complicated task;

(advancing) jam from air, which can be much more energy efficient than jamming from ground, especially if the drone can get close to the swarm — this is a considerable advantage of the FD radio technology as this would simultaneously paralyze the swarm but also complicate the localization of allied forces on the ground by the enemy (that is typically a high priority);

(scouting) use a drone for scouting (transmitting back aerial video feed) while at the same time detecting for frequency usage on the same frequencies by adversarial drones.

The aspects listed above are made possible by FD radio technology or FD significantly improves on the performance that can be achieved with conventional HD radio technology. This is the next step in radio evolution that will enable to live up to the growing list of requirements that modern EW faces in congested spectrum environments.

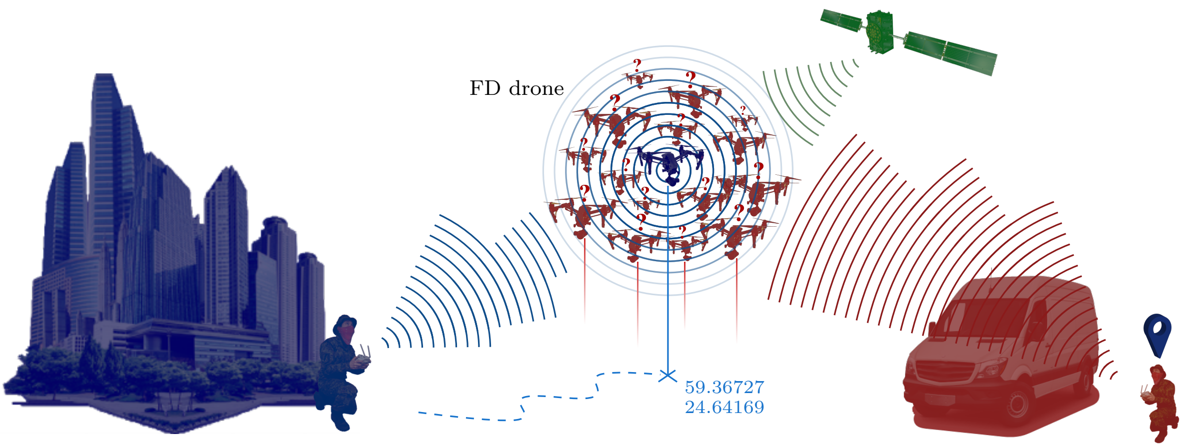

Figure 2: Disruptive full-duplex (FD) drone — the FD technology is needed for the defence drone to be able to simultaneously operate on and jam the same frequencies that are used by the adversarial drone swarm.

0.3 Roadmap For Implementation

Figure 3 gives a broad overview of the approximate timeframe that we believe is required to carry out the necessary research & development (R&D) for the technology to reach industrial roll-out maturity level. *In the 1st part (I),* the FD radio technology needs to be improved to handle higher powers and wider frequency ranges (i.e., transfer from its current state). *In the 2nd part (II),* specific applications developed by the industry can be developed. This relies on previously targeting and specifying the key applications together with security and defence experts — as the possible applications for FD radio technology go beyond counter-drone technology. It is expected that during the development of the security and defence applications, further tailoring and servicing of the SI cancellation platforms and FD knowledge needs to be done for different applications. Given that the technological concept is already verified and experimental proofs-of-concept have been reported, it is viable to have this technology incorporated into security and defence capabilities by 2030.

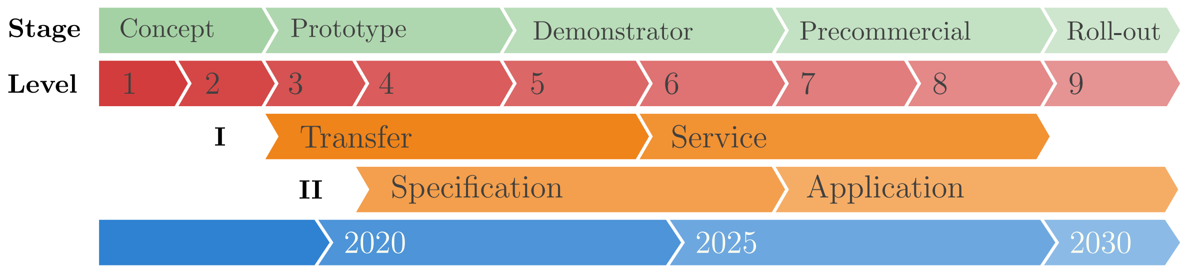

Figure 3: Technology roadmap — research and development of full-duplex (FD) radio technology for counter-drone applications with the aim of enhancing EU's defence capabilities by 2030.

References

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