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## **Glossary**

Please refer to the Glossary document, which is common for all the deliverables in nSHIELD.



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# 1 Executive Summary

At the start-up of the project, an assessment is done on the technologies that the pSHIELD project has examined, in order to full address the innovative technologies for the nSHIELD project.

In the following section the technologies examined in the nSHIELD project are described.

Part of these technologies were examined partially in pSHIELD project, nSHIELD will complete the identification of these technologies, will identify additional technologies and will explore in detail the technologies that will be classified like the more suitable to add SPD to the communication networks based on the Embedded Systems.

## 2 SPD High Level Requirements for nSHIELD System

### 2.1 nSHIELD Network

This chapter provides assessment of the technologies for SPD in embedded systems focusing on the Network layer, that have previously been studied within the pSHIELD project (see public deliverable 4.2 “SPD Network technologies prototype report”), as well as alternative technologies that have not been examined within the pSHIELD project.

Having decided that the implementation of the Smart Transmission Layer is to rely on the Software Defined Radio (SDR) platform which - once equipped with the possibilities of maintaining scenario awareness, detecting possible threats and adapting to the new situations by itself – will evolve towards the Cognitive Radio (CR), the common threats regarding SPD for these systems (SDRs and CRs) will be presented.

Overview of the proposed countermeasures and solutions for those threats will then be given.

Furthermore, the basic ideas of the self-management and self-coordination schemes for unmanaged and hybrid managed/unmanaged networks will be explained.

The ultimate goal is to come up with the set of solutions that will integrate all of the relevant mechanisms for ensuring SPD in the SDR-based and CR-based embedded systems.

### 2.2 SPD in SDRs

Smart SPD information transmission (see pSHIELD deliverable 4.1. “SPD Network technologies prototype”) is a feature of the nSHIELD system – introduced previously in the pSHIELD project – based on a Network Layer Service, usually called Software Defined Radio (SDR).

There is no unanimous definition of the SDR – however, one of the most recognizable, and in the same time very intuitive ones is Wireless Innovation Forum’s one, which recognizes SDR as “a radio in which some or all of the physical layer functions are software defined”.

These functions usually include - but are not limited to - frequency; modulation technique; cryptography; used bandwidth, coding technique, etc. However, the level of reconfigurability/reprogrammability needed for the radio to be classified as a SDR isn’t strictly defined.

The “ideal” SDR would, therefore, have all of the radio-frequency bands and modes defined in software.

Some of the major security concerns from the perspective of a mobile appliance are:

- *User identification* attempts to ensure that only authorized entities can use the appliance.
- *Secure storage* addresses the security of sensitive information such as passwords, PINS, keys, certificates, etc. that may reside in secondary storage (e. g., flash memory) of the mobile appliance.
- *A secure software execution environment* is necessary to ensure that attacks from malicious software such as viruses or trojan horses are prevented.
- *A tamper-resistant system implementation* is required to ensure security of the hardware implementation from various physical and electrical attacks.
- *Secure network access* ensures that only authorized devices can connect to a network or service.
- *Secure data communications* considers the privacy and integrity of data communicated to/from the mobile appliance.
- *Content security* refers to the problem of ensuring that any content that is downloaded or stored in the appliance is used in accordance with the terms set forth by the content provider (e. g. read only, no copying, etc.).



Several requirements were imposed on the network layer in the pSHIELD project, which transcribe to nSHIELD as well. (from pSHIELD deliverable 2.1.2. "System Requirements and Specifications"). Namely, it is stated that the network layer:

- shall be secure
- should have suitable security protocols
- should support security protocols to protect entire IP payload or upper-layer protocols
- should provide Availability, Confidentiality and Integrity
- shall support anti-replay protection to prevent against a denial of service attack
- shall support data confidentiality to protect, and to encrypt the entire data
- shall support algorithms for encryption
- shall support data integrity to ensure that the contents of the packet do not change in transit
- shall support data authentication to verify that the packet received is actually from the claimed sender
- should use the IPSec protocol
- should support more efficient algorithms for fast and better speed of execution to satisfy the conditions in the case of limited processing and power capabilities of embedded devices
- should support symmetrical cryptography
- should provide dependability mechanism
- should provide Reliability, Availability, Safety, Maintainability, and Integrity
- should provide privacy

Ensuring SPD for SDR systems involves dealing with two main issues: software-based protection and hardware-based protection.

Software-based protection schemes involve the deployment of tamper-resistance techniques to defend against malicious or buggy software installations.

These schemes also involve techniques and algorithms for the secure download and distribution of software into several SDRs.

As CRNs have to be flexible, updated software can be frequently downloaded from servers through the Internet. Secure downloading involves mechanisms that protect the integrity of the data exchanged, protect against eavesdropping, as well as providing secure authentication between the communication parties.

Hardware-based protection schemes include modules implemented in hardware acting as isolation layers between hardware and the software components.

These modules monitor several parameters of the SDR (e.g. transmission power).[5]

Several SPD mechanisms have been proposed in the literature, namely:

- Light Secure Socket Layer (LSSL) by Brawerman et al. [6] - a lightweight protocol based on the SSL protocol, but takes up less bandwidth, thus, it is more suitable for SDR handheld devices operating under low-capabilities, low-bandwidth and error-prone wireless links.

However, securing the radio configuration (R-CFG) download connection does not guarantee that a valid radio configuration, that is, a R-CFG that has been approved by the regulatory agency, has been downloaded. In order to install only valid R-CFGs, a secure download protocol is presented.

The secure protocol includes, besides the LSSL, steps of mutual authentication, public/private key mechanisms for data encryption and decryption, and fingerprint calculations to check data integrity.

Finally, the secure protocol is analysed and shown to be deadlock and livelockfree, and to properly terminate.

- Uchikawa et al. [7] - a secure download system which uses the characteristics of the field programmable gate arrays (FPGAs) composing the SDR.

The proposed system has the novelty that realization of high security enciphering is possible. This is achieved using the characteristic of FPGAs which allows systems to be arranged in a variety of different layouts, as well as by using the configuration information as the key.

This unifies the renewal of the key and the enciphering. In addition the proposed system has the merit that it has high security against illegal acquisition such as a wiretapping, and can also be used in conjunction with any other current cipher algorithm.

- Li et al. [8] - a hardware-based method where the maximum transmission power is computed and controlled by a module implemented at the hardware level of the SDR transceiver.

The advantage is that the module, which estimates the maximum transmission power, is isolated from the software layers, which can either be compromised more easily by attackers or malfunction due to software bugs.

The authors assume that SUs access the spectrum in an overlay approach; thus secondary and primary transmissions can take place at the same time.

- Secure Radio Middleware (SRM) Layer by Li et al. [5] - based on robust separation of the radio operation environment and user application environment through the use of virtualization.

A secure radio middleware layer is used to intercept all attempts to re-configure the radio, and a security policy monitor checks the target configuration against security policies that represent the interests of various parties.

Therefore, secure re-configuration can be ensured in the radio operation environment even if the operating system in the user application environment is compromised.

- Xiao et al. [9] - a tamper resistance scheme that utilizes code encryption and branch functions to alter the target program, while enabling the program to satisfy its performance requirements.

The scheme employs a technique called the Random Branch Function Call (RBFC), which enables a user to control the tradeoff between integrity checking frequency and the overhead, and consists of two phases: (i) transformation where the unprotected assembly code becomes

tamper-resistance protected offline, and (ii) verification where a code is checked for integrity violations.

The proposed scheme is designed to thwart static attacks (static information extracted by examining the software code) and to protect partially against dynamic attacks (dynamic information extracted while the software code executes).

- Brawerman et al. [10] - a framework for cloning prevention of SDR Mobile Devices. It provides a set of software and hardware technologies that along with the cooperation of a Wireless Operator (WO) can prevent cloning.

Unlike other schemes, the proposed anti-cloning framework not only detects cloned units, but also elevates the level of difficulty to clone a valid unit.

The WO in this contribution is assumed to be the manufacturer of the SDR. The cooperation is performed through an authentication process where the WO verifies that the specific SDR is the original and not a cloned one.

The framework is independent of the wireless communication technology, working well for different cellular technologies and the Internet.

## 2.3 SPD in CRNs

Although this doesn't necessarily have to be the case, Cognitive Radio is usually defined as an upgraded SDR in the sense that it is self-reconfigurable and has learning capabilities, i. e. the radio can reconfigure itself through an ongoing process of awareness (both of itself and the outside world), perception, reasoning, and decision making.

However, because of those two traits (cognitive capability and re-configurability), CR technology has also raised new threats and vulnerabilities (in addition to common threats present in traditional wireless networks AND the aforementioned SDR-specific threats).

Security is necessary in CRNs because the data channel is easily accessed by an attacker. In the context of CRNs, we define attacks as actions that achieve at least one of the following goals:

- Unacceptable interference to licensed primary users: Because of the attack, the communication channel of primary/licensed users of a frequency band is diminished or just becomes unusable (denial-of-service (DoS) attack).
- Missed opportunities for secondary users: An attacker could prevent secondary users from using available spectrum bands thus, once again, reducing channel performance or just denying service to secondary users.
- Access to private data: An attacker could try to access data in an unauthorized way. As a consequence, data must be secured by means of cryptographic primitives.
- Modification of data: An attacker could try to modify the data exchanged between several entities to its own advantage. Thus, integrity of data must be assured.
- Injection of false data: Injection of false data could make the CRN to perform in an unpredictable way or just following the attacker guidelines. Therefore, authentication of information sources should be guaranteed.

Hence, it is possible to divide CR-specific attacks with regard to what the attacker is trying to achieve, as well as which layer he is targeting. We have:

- Primary User Emulation Attacks (PUEAs)
- Spectrum Sensing Data Falsification Attacks (SSDFAs)
- Beacon Falsification (BF) attack
- Small Backoff-Window (SBW) attack
- Lion attack

### 2.3.1 Primary user emulation attacks

Primary user emulation attack (PUEA) is first identified by Chen and Park in 2006. In PUEA, an attacker occupies the unused channels by emitting a signal with similar form as the primary user's signal so as to deter the access of the vacant channels from other secondary users.

The cognitive radios have highly reconfigurable air interface which makes it possible for an attacker to modify the air interface to mimic a primary user signal's features and thereby leading legitimate secondary users to erroneously identify the attacker as a primary user.

The investigation shows that a PUE attacker can severely compromise the spectrum sensing performance and significantly reduce the channel availability to legitimate secondary users.

PUEA can compromise a cognitive radio system using either of spectrum sensing methods to attack the energy detection scheme, PUE attacker may masquerade the primary user by transmitting signal with the similar energy as primary user; to defeat cyclostationary detectors, an attacker can make its transmissions indistinguishable from primary user signals by transmitting signals that have the same cyclic spectral characteristics as primary user signals.

The fundamentals of PUEA is that the adversary is not focused on jamming primary users, but on forestalling idle spectrum bands that could have been used by other secondary users. Depending on the motivation behind the attack, a PUE attack can be classified as either a selfish PUE attack or a malicious PUE attack.

A selfish PUE attacker aims to prevent other secondary users from competing for that band by sending signals with similar characteristics to those of the primary user, whereas the malicious user launching an attack in the same manner is more interested in obstructing the whole dynamic spectrum access process rather than monopolizing the utilization of the frequency spectrum resource.

Depending on the motivation behind the attack, a PUE attack can be classified as either a greedy PUE attack or a malicious PUE attack:

- Greedy nodes that by transmitting fake incumbent signals force all other users to vacate a specific band (spectrum hole) in order to acquire its exclusive use.
- Malicious nodes (adversaries) that mimic incumbent signals in order to cause Denial of Service (DoS) attacks.

Malicious nodes can cooperate and transmit fake incumbent signals in more than one band, thus causing extensive DoS attacks making a CRN hop from band to band, severely disrupting its operation.

Furthermore, adversaries could also cause DoS attacks to PU networks by creating harmful interference.[5]

Considering different adversaries, assumptions whether the location of users are known, whether cooperating schemes between SUs are used or not, and if FCC's mandate that no modification to incumbent signal is necessary has been followed, several PUEA combating techniques have been proposed (and tested) in the literature:

- Chen et al. [13] – a transmitter verification scheme - called LocDef (localization based defence) - is proposed, which verifies whether a given signal is that of an incumbent transmitter by estimating its location and observing its signal characteristics.

To estimate the location of the signal transmitter, LocDef employs a non-interactive localization scheme.

This approach consists of three phases: (i) verification of signal characteristics, (ii) received signal energy estimation, and (iii) localization of the transmitter. It mainly focuses on the localization of the transmitter using a method based on RSS measurements collected by a wireless sensor network.

Based on the distribution of the RSS values, a decision is made about if the transmitter is an incumbent transmitter or an attacker.

Here, the location of the incumbent transmitter has to be known a priori.

However, the proposed method has several limitations, such as the use of RSS (which can have large fluctuations); the assumption of using fixed transmission power (not taking sophisticated adversaries into account) and the need for the location of the incumbent transmitter to be known a priori.

- Jin et al. [14] - present an analytical model as well as a practical mechanism to detect PUEAs without using any location information.

An analysis using Fenton's approximation and Wald's sequential probability ratio test (WSPRT) to detect PUEA is given.

The detection mechanism allows the user to set thresholds on probability of missing the primary user and the probability of successful PUEA and hence can accommodate a range of sensitivities.

It is possible to construct tests that always keep the probability of missing the primary user below a specified threshold, while still keeping the probability of successful PUEA low.

Mathematical expressions are derived for the computation of: (i) the Probability Density Function (PDF) of the received power to a SU due to a PU, and (ii) the PDF of the received power to a SU due to malicious users.

Then, WSPRT is used to make a decision between two hypotheses (H0: primary transmitter, H1: malicious user).

In [15] same authors compare the results produced by WSPRT with those produced by using Neyman-Pearson Composite Hypothesis Testing (NPCHT), also taking into account multiple malicious users, as well as the fading characteristics of the wireless environments.

According to their simulations, WSPRT achieves a 50% better efficiency in terms of detecting PUEA.

- Chen et al. [16] - authors characterize an advanced primary user emulation attack and an advanced countermeasure against such an attack.

Specifically, they show that both the attacker and the defender can apply estimation techniques and learning methods to obtain the key information of the environment and thus design better strategies.

They further demonstrate that the advanced attack strategy can defeat the naive defence technique that focuses only on the received signal power, whereas the advanced defence strategy that exploits the invariant of communication channels can counteract the advanced attack effectively.

A key observation stated by the authors and used in this method is that an attacker can mimic many characteristics of a PU signal, but it cannot easily emulate the feature of the communication channel.

SUs perform energy detection as this method, according to the authors, has three advantages: (i) it is easily implemented, (ii) a sophisticated attacker can emulate several characteristics of the primary signal such as cyclostationary characteristics and modulation; thus it would be more difficult for a SU to detect the attack when using the matched filter or the cyclostationary spectrum sensing approaches, and (iii) the method proposed here can be extended for the other spectrum sensing methods.

- Liu et al. [21] - authors propose a novel approach for authenticating primary users' signals in CRNs, which conforms to FCC's requirement.

This approach integrates cryptographic signatures and wireless link signatures (derived from physical radio channel characteristics) to enable primary user detection in the presence of attackers.

Essential to the approach is a helper node placed physically close to a primary user. The helper node serves as a "bridge" to enable a secondary user to verify cryptographic signatures carried by the helper node's signals and then obtain the helper node's authentic link signatures to verify the primary user's signals.

A key contribution is a novel physical layer authentication technique that enables the helper node to authenticate signals from its associated primary user.

Authors state that, unlike previous techniques for link signatures, their approach explores the geographical proximity of the helper node to the primary user, and thus does not require any training process.

The authors also demonstrate a real implementation of the proposed approach using GNU radios and verify some of their simulation results.

### 2.3.2 Spectrum Sensing Data Falsification Attacks

Several transmission features such as signal fading, multi-path, etc., can cause the received signal power to be lower of what path loss models have predicted. This leads to undetected primary signals and harmful interference to PUs.

There are two types of fading: shadow fading that is frequency independent, and multi-path fading that is frequency dependent.

Shadow fading can cause the "hidden node" problem where a SU, although located within the transmission range of a primary network, fails to detect primary transmissions.

SU1 fails to detect the transmission of incumbent signals because of shadow fading, so it accesses the incumbent frequency band causing harmful interference to PU1.

A solution to this problem is the collaborative spectrum sensing technique, where a number of users sense the environment and send their observations to a fusion centre (FC).

FC then fuses the provided information taking the final decision regarding the presence or absence of incumbent transmissions.

Another type of sensing is the collaborative distributed sensing where no FC is used. In this case, each SU makes its decision based not only on its observations but also on observations shared by other SUs.

For both types of collaboration, distributed or centralized, SUs have to share their observations or transmit them to a FC.

There is always the possibility that one or more SUs send false observations, intentionally or unintentionally. Similarly to PUEAs, nodes sending false observations can be categorized as follows:

- Malicious users that send false observations in order to confuse other nodes or the FC. They aim to lead FC or the rest of the nodes to falsely conclude that there is an ongoing incumbent transmission where there isn't, or make them believe that there are no incumbent transmissions when there are.

In the first case, the legitimate SUs will evacuate the specific band, while in the second case they will cause harmful interference to the PUs.

- Greedy users that continuously report that a specific spectrum hole is occupied by incumbent signals. The goal of these users is to monopolize the specific band by forcing all other nodes to evacuate it.
- Unintentionally misbehaving users that report faulty observations for spectrum availability, not because they are malicious or greedy, but because parts of their software or hardware are malfunctioning. The reason for this can be a random fault or a virus.

Regardless of the type of the misbehaving users, the reliability of collaborative spectrum sensing can be severely degraded by faulty provided observations.

This is called as Spectrum Sensing Data Falsification (SSDF) attack. FC receives observations from SUs and then it decides about the presence or absence of primary transmissions.

This type of cooperation can be exploited by malicious users that send malicious reports to the FC on purpose.[5]

Some of the contributions for the detection of SSDF attacks – mutually differentiated by type of reporting (binary vs. continuous), fusion rules used (AND-rule; OR-rule; average-rule; Dempster-Shafer etc.) are:

- Wang et al. [18] – develop a malicious user detection algorithm that calculates the suspicious level of secondary users based on their past reports.

Then, the trust values as well as consistency values are calculated and are used to eliminate the malicious users' influence on the primary user detection results.

Through simulations, it was shown that even a single malicious user can significantly degrade the performance of collaborative sensing.

The proposed trust value indicator can effectively differentiate honest and malicious secondary users.

For the evaluation of this scheme the authors compare their approach using different fusion rules (OR, K2).

They also show how their approach can increase the detection probability and decrease the false alarm rate significantly when the OR rule is used compared to an attack-oblivious method. However, only one adversary has been considered.

- Rawal et al. [19] - The authors propose a method to identify attackers by counting mismatches between their local decisions and the global decision at the FC over a time window and then remove them from the data fusion process.

Hence, for the computation of the reputation metric the output of each SU is compared to the decision made by the FC.

If there is a decision mismatch, the reputation metric of the corresponding user increases by one. The smaller the reputation metric is, the more reliable the user is.

If the reputation metric of a user exceeds a predefined threshold, its decisions are isolated and thus not used by the FC.

This work is somewhat similar to, [18], but the key difference is that the reputation metric is restored in case a node temporarily misbehaves.

- Noon et al. [20] - a hit-and-run attack policy is proposed, which cannot be mitigated by traditional approaches of attacker detection in cognitive radio systems.

Motivated by the system of points for penalizing reckless drivers in DMV, a point based attacker detection algorithm is proposed, whose effectiveness is demonstrated by numerical simulations.

The adversary is an intelligent attacker that, by knowing the fusion technique used by the FC, deviates between an honest mode and a lying mode.

The attacker estimates its own suspicious level and as long as it is below a threshold  $h$ , it reports faulty observations (lying mode). If its suspicious level drops below a threshold, it behaves legitimately again (honest mode).

The detection scheme functions in a way that when the suspicious level of a node becomes larger than  $h$ , a point is assigned to this user.

When it exceeds a predefined threshold, the observations of this user are ignored permanently. A drawback of this method is that a user is permanently removed from a CRN if it collects enough points.

- Kaligineedi et al. [21] - authors have devised schemes to identify and nullify the effect of malicious nodes for the case where energy detectors are used by the sensing devices.

A simple and fast average combination that's using a pre-filtering phase based on quartiles is presented.

Then, a trust factor is computed over a sample period that identifies more outliers. Using simulations, it was verified that the proposed schemes can identify 'Always Yes' users, 'Always No' users and malicious nodes producing extreme values.



- Min et al. [22] – an attack-tolerant distributed sensing protocol (ADSP) is proposed, under which sensors in close proximity are grouped into a cluster, and sensors in a cluster cooperatively safeguard distributed sensing.

The heart of ADSP is a novel shadow fading correlation-based filter tailored to anomaly detection, by which the fusion center pre-filters abnormal sensor reports via cross-validation.

By realizing this correlation filter, ADSP minimizes the impact of an attack on the performance of distributed sensing, while incurring minimal processing and communications overheads. This approach consists of two phases.

First, pre-filtering takes place where possible outliers are isolated and the information they provide is ignored by the FC.

During this phase, a per-sample abnormal behaviour is detected by examining similarities using the Conditional Probability Density Function (CPDF) of the power for the sensors belonging to the same cluster report.

If CPDF lies between two defined thresholds, the SU is characterized as legitimate, otherwise it is tagged as an outlier and its reports are ignored.

As the authors note, this pre-filtering step is not adequate in very low SNR environments due to the high sensitivity of the fusion decision to RSS values.

For this reason, a second line of defence follows where a weighted gain combining method assigns weights to the outputs of the sensors based on their CPDF.

The FC accumulates the reports sent by all sensors (excluding the users identified as outliers in the pre-filtering phase) and if the total output exceeds a threshold, the frequency band under examination is marked as busy, otherwise it is marked as vacant.

### 2.3.3 Spectrum Sensing Data Falsification Attacks

In some approaches, a dedicated channel is used to exchange sensing information:

- between the base station and the secondary users if the CRN is centralized (i.e. DIMSUMnet) and
- between secondary users if it is distributed (such as KNOWS or CORVUS)

A malicious user could jam this channel, disrupting all transmissions and preventing elements within the CRN from sharing information about spectrum usage.

The lack of knowledge about available bands keeps the CRN from operating (DoS attack). Moreover, eavesdropping on the control data provides the attacker with all the required information to detect which new channel the CRN is switching to.

The need of securing the common control data is hence patently obvious. 802.22 Working Group is aware of this threat and has proposed mechanisms to protect such information.

We consider that the impact of this attack is more relevant in centralized CRNs as an attacker can focus on jamming the control channel within the base station vicinity (single point of failure) and thus easily affecting the whole network.

The threats that a CCC faces can be categorized as follows:

- MAC spoofing, where attackers send spurious messages aiming to disrupt the operation of CRN (e.g. channel negotiation).

Multi-hop CRNs are more vulnerable to this type of attack as there is no central entity to control the authentication between the nodes and protect data integrity.

- Congestion attacks, where attackers flood CCC in order to cause an extended DoS attack.
- Jamming attacks, where attackers cause DoS attacks at the physical layer by creating interference.

Some of the contributions dealing with the attacks targeting the CCC are:

- Bian et al. [23] – the authors show how DoS attacks using spurious MAC frames affect the performance of a multi-hop CRN.

The degree of degradation is heavily affected by the number of the attackers.

The same work studies the effect on network performance when nodes act selfishly. In a multi-hop CRN, selfish nodes that are located along the path of normal-behaved nodes can drop their packets; thus monopolizing the medium.

- Safdar et al. [24] – the authors present a novel framework for providing common control channel security for co-operatively communicating cognitive radio nodes.

It is investigated how two cognitive radio nodes can authenticate each other prior to any confidential channel negotiations to ensure subsequent security against attacks.

### 2.3.4 Beacon Falsification Attacks

Beacon Falsification (BF) attacks is the set of attacks specifically targeting the MAC layers within the IEEE 802.22-based networks.

The attacks consist of disrupting the exclusive spectrum sharing by transmission of spurious beacons that contain very large CCN values by an adversary.

To counter BF attacks, Bian et al. in [20] propose an inter-cell key management scheme.

### 2.3.5 Cross-layer Attacks

“Cross-layer” attacks refer to attacks that target multiple layers of the CRNs, and can affect the whole cognitive cycle, as attacks at all layers become feasible.

Small Backoff Window (SBW) is a very common attack in wireless networks where malicious users choose a very small value for minimum Contention Window (CW<sub>min</sub>) aiming to monopolize bandwidth. SBW attacks are feasible against CRs with MAC layers using a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) type of access.

Wang et al. in [25] study specific attack, time domain coordination of RFSD and SBW. A cross-layer trust defense scheme was designed by developing (1) abnormal detection schemes in PHY and MAC layers and (2) the cross-layer trust manager.

The simulations showed how this scheme fares against this specific cross-layer attack.

The Lion attack is defined as a jamming targeted to reduce the throughput of TCP by forcing frequency handoffs.

The handoff process involves sensing the medium looking for vacant channels and choosing the best one according to some criteria, thus incurring high latencies until the transmission is resumed.

A malicious user trying to disrupt a TCP connection of a secondary user can perform a PUEA to force a handoff in the CRN.

As the transport layer is not aware of the disconnection, it keeps sending data segments which are queued at lower layers but not transmitted and thus TCP segments can be delayed or even lost.

As the TCP sender is allowed to transmit new data upon reception of acknowledgments, loss or delay of segments can lead to a period of inactivity of the former.

Hernandez-Serrano et al. in [26] evaluate the impact of the Lion attack on TCP performance through an analytical model.

The model provides an expression for the average time of inactivity of a TCP sender due to the attack and also the percentage of inactivity, parameters which measure the impact of the attack on TCP throughput.

However, for mitigating the attack, only general recommendations are given, such as: making TCP layer aware of the cognitive capability of CRs so it acquires information from the physical layer, and securing the operation of a CCC for channel negotiations during the attack.

## 2.4 Cognitive Radio Node Simulator

In pSHIELD began the implementation of a Cognitive Radio Node that is able to receive radio parameters from moving hosts and automatically detect possible threats.

The Hardware and the Software of this platform will evolve during nSHIELD project, first adopting a smaller and more powerful HW that can support the evolution of the cognitive algorithms, allowing the studies and the experimentations of new concepts and features.

The internal architecture of the Node is able to learn typical safe environment features, thus detecting the presence of external attackers by analysing radio parameters.

In a considered scenario, the cognitive node always updates the radio parameters (SNR, BER and Transmitter Power, PTX) for the self-awareness purposes.

There are some specific provisions considered to design this kind of simulator used for the Security, Privacy and Dependability (SPD) in the context of integrated and interoperating heterogeneous applications.

When the agent enters the scene, the cognitive node becomes aware of the radio parameters of the agent either by using the spectrum sensing technique or from a direct communication with the agent itself. In this way the node can update its radio information in order to use the radio resources efficiently and securely.

The cognitive node has an internal knowledge of all of the radio parameters which would be considered in the selected environment and their respective variation models.

From the configuration database, the node knows which frequencies are being used by which agent, as well as which ones are free to use.

If the new agent enters the scene whilst the communication is ongoing, the cognitive node senses the radio parameters of the agent and is able to modify and adapt agents' radio parameters when necessary.

In the presence of the jammer at specific frequency in a cluster, the cognitive node sends the message to the agents to adjust the radio parameters properly, i.e. by changing either the frequency or the transmission power (spread spectrum or noise based data transmission of signals).

An image of the simulator in consideration is shown in the following figure. In the scene, there are two entities, both with active communication on different frequencies.

Areas affected by the movement of such entities are three jammers that inhibit different frequencies and present a range of different from each other.

Moving agents in the scene and the presence of jammers are dynamically created through the dedicated simulator.

The simulator sends to the cognitive node the positioning data, namely the trajectories of the agents (like a tracker) and radio data describing the situation.

More specifically, each agent is controlled by the cognitive mobile node - considered as an entity - after the registration process in the area under observation periodically sends information regarding the quality of communication.



**Figure 1: Simulator - considered scene (Jammer, First Agent and Second Agent in the scene)**

In the simulator there are six types of interaction considered between two different agents (guard/intruder), namely:

- a) 'Agents in Motion': Two entities with communication capabilities moving in the scene without interacting with each other. One may be the network and the second a new communication node.
- b) 'Guard-Intruder Agents': one or more communication nodes belonging to the network is the guard and the other is the intruder.

When the guard spots the intruder inside the region under its control, it starts the procedures to identify and localize the menace in order to counteract the action of the intruder whereas the intruder tries to overcome the countermeasures quickly.

- c) 'Meeting Agents': Two communication entities meet/gather inside the scene and after meeting they link together.
- d) 'Leave & Meet Agents': Two communication entities link inside the scene and leave the area individually.
- e) 'Running Agents': Two communication entities running inside the scene but without interacting with each other.
- f) 'Run & Walk Agents': One is running inside the area under consideration and the other is walking but without interacting with each other.

In order to give an idea of what will be tested through the mentioned mixed HW-platform+simulator environment, the following is an example about a concept that was identified and preliminary verified in pSHIELD and that will be exploited in nSHIELD.

These tests will demonstrate the value added by the Smart Transmission Networks to the SPD functionalities, compared with the traditional behaviour of a Cognitive Radio Node:

A node that would like to belong to the nSHIELD SPD network first must transmit its GPS position.

All the nodes continuously measure and transmit the value of the strengths of the radio signals (RSS) they're receiving.

Each SPD node has the ability to fuse the data received from the other nodes, so, comparing the new 'guest' position declaration with the RSS of the other trusted nodes, together with their position, it can decide if this guest may be 'malicious'.

## 2.5 Reputation in network layer – Mechanisms

There are many reputation mechanisms that have been deployed across network layer; the following section describes some of them:

**Reputation for ad-hoc networks**<sup>1</sup>: Ad-hoc networks are intrinsically dynamic and thus many unexpected elements can be added dynamically putting in risk the purpose of the network.

The purpose of this work is to provide a mechanism for detecting malicious incorrect packet forwarding attacks.

To this end, a trust model extending routing protocols and based on the reputation concept is developed the model provides two main functionalities: monitoring the behaviour of the neighbouring nodes in the network and computing their reputations based on the information provided by the monitoring.

**Selfish nodes isolation**<sup>2</sup>: This mechanism provides a distributed reputation evaluation scheme implemented autonomously at every node in an ad hoc network with the objective of identifying and isolating selfish neighbours.

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<sup>1</sup> Yacine Rebahi, Vicente .E Mujica-V, Dorgham Sisalem Fraunhofer Fokus, Kaiserin Augusta Allee 31, 10589, Germany, 2004

<sup>2</sup> A Reputation-based Mechanism for Isolating Selfish Nodes in Ad Hoc Networks, M. Tamer Refaei, Vivek Srivastava, Luiz DaSilva, Mohamed Eltoweissy, 2005

Each node maintains a reputation table, where a reputation index is stored for each of the node's immediate neighbours.

This protocol provides routing protocol independence, no communication overhead, directional transmission and elimination of an overlay trust management (this just on of the main difference compared to nSHIELD overlay layer which will compose trust)

**Reputation for wireless networks**<sup>3</sup>: this work encompasses several algorithms brought from the game theory.

It uses the game theory itself (prisoner dilemma), strategies and pay-off and Nash equilibrium in order to develop reputation based techniques. These are usually very interesting for many elements.

### 2.5.1 Main Attacks in Reputation-based network layer

Reputation based techniques enable some new interaction with different and normally external network elements. This causes new risk that must be detected. The following attacks are the main risks that could be exploited:

**Spoofing**: it could happen that one person or software might attack the ARP table on Ethernet layer. The aim is to associate attacker's MAC address with the IP address of another host, so that there is a masquerade action.

This would let the attacker to intercept data frames and act as an opening for other malicious attacks such as DoS or man in the middle.

There are 3 main safeguards related to Spoofing attack: mapping statically MAC and IP addresses, which it makes more complex its management, deploying ad-hoc ARP spoofing detection software and/or being helped by the OS security.

**ID Stealth**: This is a variant of the spoofing attack. One attacker might take advantage of the reputation of one element in the network if its ID is stolen. This is an opening for further malicious attacks the hacker may perform. ID steals happen if a *man in the middle* occurs and it might cause a great impact.

**Shilling**: although this attack is oriented to peer-to-peer networks, it might also happen in embedded networks.

This is about making a resource more valuable that it really is. It starts when multiple elements or instances give value to one particular resource in the network.

This element will acquire a virtual reputation and therefore present a better curriculum although it might happen that it is vulnerable.

The other elements of the network will interact with this revaluated element and consequently will put on risk themselves.

Shilling is a social attack and is very interesting for analysing the network elements behaviour according to reputation.

As countermeasure, systems should analyse how rapid one element should acquire a good reputation. This is so because rapid reputation acquisition often implies risk.

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3 Performance Analysis of Reputation-based Mechanisms for Multi-hop Wireless Networks, Fabio Milan

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## 2.5.2 Reputation in nSHIELD

nSHIELD will use reputation based techniques.

This will be based on the parameter of level agreements that systems and elements will expose as interface to external environment.

These parameters, in turn, will be based on metrics that will be defined in deliverable 2.5.

## 2.6 Intrusion Detection Systems in WSN

A WSN is a network compounded by small embedded systems that gather information from its sensor, make a set of computations and communicate via wireless links with other nodes.

These nodes can be deployed in many environments and each environment has its own needs. For example, in hostile ones WSN need to be secure and trustworthy, while in unattended environments they need to be autonomous and self-sufficient.

Due to these reasons the complexity of sensors may vary significantly, from small computation power with low energy consumption to large nodes with complex systems used in military environments. But in most cases nodes are designed as simple as possible to minimize production costs and reduce power consumption.

Because nodes are often responsible for managing critical systems, security becomes one of the most important features in WSN. In hostile environments an adversary can manage to compromise one or more nodes, and the security systems have to minimize the damage. Prevention methods like encryption and authentication can reduce intrusions but not eliminate them.

These methods cannot defend the system from compromised nodes that are already part of the network and thus use proper private keys.

Security research assumes that weak links, which can be exploited, can always exist in the network, no matter how many intrusion prevention policies are established. The undetected weak links provide the attackers a point to provoke network failures.

If a system is able to detect the intruder soon enough, appropriate measures can be taken before any damage is done or any data is compromised. In this area, intrusion detection systems are responsible for detecting a possible attack and minimizing the risks.

Due to these reasons an IDS for WSNs needs to have some specific characteristics, and some of these specifications that an IDS should have are the following:

- The IDS should not introduce a new weakness in the WSN.
- The IDS should run continuously and remain transparent to the system and users.
- The IDS agents cannot consume so much bandwidth and resources from the node.
- It must be fault tolerant and be able to recover from system failures.
- It must be able to respond to attacks without human intervention.

During the last few years, some works have been published where intrusion detection systems were applied in WSN environments [27] [28] [29]. Most of these studies have covered the local detection problem, where nodes detect specific attacks that happen in their network.

A description of the requirements of a WSN oriented IDS is given in [30]. Embedded systems, by definition, must use the minimum resources possible to preserve their lifetime. One of the main characteristic is that it must work with only localized and partial data due to the possible lack of centralized points with a global view.

Other characteristics are that the system can never trust any node completely and that the system should be fully distributed. Finally, it should be able to withstand an attack to the IDS itself.

Similar IDS are proposed in [28] and [31], where there are special purpose nodes in the network which are responsible for monitoring other nodes. They listen to messages in their same radio range and store message fields that can be useful to an IDS running in a sensor node.

There are some other different points of view in the design of IDS in WSN, for example [32], where nodes are selfish and try to preserve their resources at expense of others. Other works,[33] and [34], keep the idea of no collaboration among sensor nodes and assume that the ad hoc network routing protocols can be applied to WSN.

A distributed intelligent agent-based system is proposed in [35]. It detects intrusions in a fully distributed way. This characteristic comes from the fact that all nodes have an independent IDS agent installed. This agent is able to detect intrusions locally, always based on data collected by the same node and by neighbour nodes. Once an intrusion is detected, the responses or actions taken to isolate it are based on a decision that is made collaboratively by the set of participating nodes. Other collaborative approaches on the local detection of selective forwarding and sinkhole attacks can be found in [36] and [37] .

Intrusion detection in ad-hoc networks has had more attention as described in [38] . Distributed and collaborative IDS architectures are preferable for these networks.

This way, detailed distributed designs, actual detection techniques and system performance have been more deeply studied. It must be taken into account that wireless sensor networks compared to ad-hoc networks are generally much more resource constrained. Approaches to a more sensor collaborative system rather than a specific attacks detection system can be found in [27].

Regarding distributed systems, LIDeA is a lightweight WSN oriented IDS [39] . It is based on a distributed architecture, where nodes listen to their neighbour nodes and collaborate with each other in order to detect an intrusion successfully. LIDeA, uses components and interfaces of TinyOS [40], a free and open source component-based operating system and WSN oriented platform.

Another distributed IDS is presented in [41]. In this work a misuse-based combined with anomaly-based IDS in a two level distributed hierarchy is proposed. There are two main parts in this IDS: The IDS Central Agent, which is in charge of recognizing attacks by exploiting control data and alarms sent by Local Agents (LA), and the IDS Local Agent which is located in each node.

This LA is compound by other three parts, the Local Packet Monitor (it is in charge of analysing the traffic flowing through the node), the Control Data Collector (gathers measures to be sent to the IDS Central Agent) and the Local Detection Engine (it is in charge of detecting suspicious activities and rising alerts, receiving responses from the Central Agent and performing possible recovery actions).

The usage of an anomaly-based approach for local detection might result in a high number of false positives. The usage of temporary local decisions allows the mitigation of such sided effect and especially avoids the triggering of responses for intermittent anomalies.

The temporary decisions made by the Local Agent may be made persistent by the Central Agent. The Central Agent detects attacks based on known patterns of attack features (misuse-based detection), and when it makes its final decision, the base station propagates the decision to the Local Agents for its enforcement.

Finally a Hybrid Intrusion Detection System (HIDS + NIDS) has been proposed in [42]. This system is based on a hybrid star architecture and applied to Cluster Wireless Sensor Networks (CWSN) where intrusions are detected by Cluster Heads. The proposed IDS consist of anomaly detection and misuse detection model.

It filters a large number of packet records, using the anomaly detection model, and performs a second detection with the misuse detection model, when the packet can be determined as an intrusion. Therefore,



it efficiently detects intrusions and avoids the resource waste. Finally, integrates the outputs of the anomaly detection and misuse detection models with a decision making model.

This determines the presence of an intrusion, and classifies the type of the attack. The output of the decision making model is then reported to an administrator for follow-up work. This method not only decreases the threat of having successful attacks in the system, but also helps the user handle and correct the system further with hybrid detection.

A similar Hybrid IDS is presented in [43], where the system is based in anomaly and misuse techniques. The attacks are detected through the collaboration of global and local agents integrated in the application layer of nodes. A defence method and four algorithms to detect and isolate malicious nodes are also proposed.

## 2.7 Reputation and Trust-based IDS in WSN

In recent years a growing number of studies have been conducted on the use of reputation systems in sensor and adhoc networks [19]. But only RFSN [20] and DRBTS [21] have focused on the use of reputation systems in WSN.

DRBTS stands for “Distributed Reputation and trust-based Beacon Trust System”. This model makes use of some special nodes called Beacon Nodes (BN) that can monitor each node around and report to the rest of the network of gathered information.

This data is gathered using watchdog mechanism, this mechanism is used assiduously in WSNs and is explained in [22].

Meanwhile RFSN or Reputation-based Framework for Sensor Network is a design based on the watchdog mechanism as well, but this design keeps this mechanism in each node of the network.

Making use of this, a node can classify each action as a cooperative or non-cooperative creating the reputation of the nodes around.

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