Abstract—Using wireless sensor network (WSN) for building new sensing and actuating applications in space and extreme environments (SEE) can fuel a new application paradigm if it can be adopted into a new strategy. This complementary contribution from the Guest Editors carries an important message of breaking away from conventional WSN research and developments and adopting a heterogeneous agile unconventional wireless sensing (UWS) approach deployment. For this, we urge the use of lightweight WSN known as wireless sensor systems (WSS) to develop optimized solutions for SEE. This paper also discusses some critical technologies of WSS-SEE and includes three key aspects of a new approach to examine: 1) the characterizes of SEE; 2) potential applications of UWS; and 3) heterogeneously nature of the applications. A further clarification for deployment of UWS is demonstrated using a table with six groups of typical application areas from the recent publications media.

Index Terms—Wireless sensing, wireless sensor systems, WSN, space, extreme environments, unconventional wireless sensing (UWS), heterogeneous sensor systems.

I. INTRODUCTION

FOLLOWING the successful start of wireless sensor network (WSN) at the end of 20th Century wireless sensing moved from strength to strength seeking new positions for practical potentials, and new breakthrough applications over the last decade. In this period we have seen a variety of associated terms including wireless sensor systems (WSS), wireless sensor and actuator networks (WSAN or WiSAN [1]), wireless underground sensor networks (WUSN), underwater wireless sensor networks (UWSN), wireless smart intelligent sensing (WSIS), wirelessly-connected distributed smart sensing (WDSS), wireless body sensor mesh network (WBSMN), space sensor/surveillance network (SSN), unmanned aerial vehicle sensor networks (UAVSN), Industrial Wireless Sensor Network (IWSN). There are many more ideas all contributing to opening further possibilities for research. The incorporating technologies including wireless broadband, ultra-band, Internet and new unstructured networking such as dynamic ad hoc down to and interfacing various devices for integrating advanced old and new interconnected devices, including radio-frequency identification (RFID), internet of things (IoT), micro-electro-mechanical (MEMS) and nanotechnology devices contributing to widening the scope of research opportunities.

One economically sensitive success story comes from emerging medical devices and instrumentations for a wide range of medical applications with smart shirts, low complex smart clinic and operational theatres for remote sensor-rich risk-free operations.

There are many more successful projects, however, the real impact comes from the large-scale common problems and burning issues that needed attention, difficult cases and risky areas. The innovative solutions for urgently needed practical applications such as video surveillance systems, space mission programs, many structural health applications, and many urgently needed underwater projects to include and activate under agile small-scale WSN applications. At clustering and networking level one cannot just assume all the nodes can enjoy ideal communication media. For example, a complex WSN working in the moderate temperature of Europe will not last very long in a South American humid bushy environment. It may not work either in the hyper-arid climate of the North African desert. To this effect finding many solutions for our most needed ‘space and extreme environments’ (SEE) applications is quite limited [2]. In other words, the conventional very large homogeneous WSN solutions cannot help to explore most scientific and industrial opportunities [3], [4].

A. WSS for HSWS

Looking for dynamic solutions to settle the WSN paradigm is like a rapidly growing, rolling snowball. We notice many practical developments are hampered under the existing ground WSN rules.

Part of conventional WSN problem is due to the growing need for small, agile, and self-managed heterogeneous smart wireless sensing (HSWS) solutions. It may be worth mentioning that a WSN normally, as in smart dust, represents a very large number of homogeneously smart sensors cooperating through various forms of clustering to gain desirable sensitive information from a media or environment through
B. Unconventional Wireless Sensing

adoption new technologies. Without loss of generality we call these smart sensing technique ‘conventional WSN’. However, there are many practical applications required to make use of different nodes with different capabilities for different requirements such as actuators, accelerometers, or different sensing that cannot be effectively interconnected. Therefore neither networking nor clustering would be the same as homogeneous large networks. We call such a heterogeneous complex network ‘unconventional WSN’.

In order to characterise the new HSWS solutions let us divide the applications of WSNs based on their uses into two complementary groups of (a) ‘conventional WSN’ addressing the large application scenarios that normally use homogenous and generic smart sensors and (b) ‘unconventional WSN’ for all other specific applications which come under HSWS systems.

The second group of applications, dedicated HSWS, however, can enjoy the driving forces of SEE and in effect comprise virtually all SEE applications. Further clarification is due to the fact that WSS represents a system rather than a network for small and agile application-specific solutions. We therefore, count the following advantages for adopting WSS:

1. Due to its application based optimization approach the cost and complexity for the overall system could be kept at a minimum, far below conventional WSN
2. An integrated approach to multi-resource sharing can help with performance and quality of operation
3. A higher degree of freedom at application specific levels would help with fault and associated topological issues
4. Consideration of an overlay control mechanism would enable better, long-term maintenance and regular modifications upon exchange of fewer parameters.

B. Unconventional Wireless Sensing

The design features provided by WSS platforms for HSWS can enjoy all complex sensing and actuating systems. This feature, beneficial in most cases, however, could weaken the system in order to perform under SEE constraints. Therefore further harnessing of the WSS to work under severe conditions applies to some SEE applications which means we need to apply a few further critically important refinements under the WSS-SEE flagship by adopting the extra restrictive requirements of an unconventional environment in the design process towards an ‘unconventional wireless sensing’ (UWS) solution. That is, another rejuvenating directed move into a better position to reactivate more useful research and development as required which is essential to inject flagship breakthrough applications where both academics and industries can visualise the real potentials of wireless sensor platforms that can only happen under new unconventional applications.

In order to locate a suitable placement to accommodate the UWS approach for a new application paradigm we need to redefine SEE or more appropriately EE in its compact format. For this we look further into the word ‘environment’.

One is for living conditions, ‘human living environments’ are usually classified as: acidic, alkaline, astrobiology, extremely cold, extremely hot, hypersaline, space, under pressure, under water, under heavy radiation, without water (waterless), without oxygen, without air (airless), and all other places on earth or beyond in short supply of basic needs for human survival, see [5]. Another is for the way we use it for systems, which represent an environment as the scope of our investigation.

As mentioned earlier for WSN we prefer to use the term ‘conventional’ instead of ‘classic’ or ‘normal’ for the environment as well.

The following are some examples for wireless sensing systems working under the definition of ‘EE systems working parameters operating beyond conventional conditions’:

- Space represents an EE due to its unpredictable features. For aerospace wireless sensor technology we can add to the list of possibilities out of scale distances between the systems with serious propagation problems, LOS, lack of air pressure, and variable gravity, they all must work under the energy scarcity. Although all systems are tested in the Laboratory and in a terrestrial earth environment they may not behave in the same way under extremely low pressure, different gravity and without atmosphere during the mission. Due to the extensive cost of any possible failure, NASA, for example, uses Skylab in space and underwater facilities (NEEMO) for testing space parts, components, and systems before their final assembly as well as other activities. The man-made satellites are a dominant potential for being upgraded with better use of wireless sensors. Now, with thousands of them, many under-used, if equipped with sensors and used properly they could improve human life on earth significantly. Most aeroplanes really need better wireless sensing.
- The systems working underwater or immersed in any fluid represent EE. The classic terrestrial EM radio waves are not suitable for such environments therefore other less developed wireless techniques such as acoustic and ultrasound should be deployed. Most importantly, the underwater systems face the possibility of being interrupted by natural movements, and obstacles, if unmanned or remotely supervised. It may be worth mentioning that due to the remoteness of access to deep-ocean any wirelessly operated sensing requires possible encounters with rigid enclosures, which could degrade the signal. All these and many other practical factors make underwater systems behave very differently from the conventional environment. Typical cases are underwater surveillance, marine ecology, and offshore exploration [6].
- Extending the use of smart sensors in the ground, hidden, or covered in other places can enable many new and advanced applications such as securing mines and improved agriculture where such uses of strong cover create EE conditions [7].
- Medical applications of WSS due to their special working conditions can mostly be regarded as EE. EE medical cases are many and scope for applications are plenty and versatile. WSS medical applications often require secure and reliable connectivity of various systems and devices
to work properly. Sensitive operations require an extra measure of confidence for a fully functional condition throughout the operation. One may consider that ‘smart shirts’ using wireless connectivity should be examined under EE requirements [8], [9].

- WSS applications involved in heavy and sensitive industrial environments such as oil wells, refineries, chemicals, hazardous, and atomic energy where safety would require special attention. Industrial disasters, surveillance, and emergency applications impose particular difficulties associated with time where speedy process and certain measures of sequencing events and actions impose particular requirements. It is here a designer should consider a special EE. Antarctica and other extremely cold spots and places on earth as is the case with hot and arid areas that in fact cover some third to a quarter of the surface of planet earth represent EE [10].

In order to gain a better insight for ‘EE’ working systems for our UWS approach let us take three simple steps for redefining system’s working environment: (1) Separate the systems working environment from humans, (2) Expand the specifications of the ‘environment’ into a dynamic form of system working environment from humans, (3) Separate the systems working environment: (1) Separate the systems working environment from humans, (2) Expand the specifications of the ‘environment’ into a dynamic form of system working environment from humans, and (3) Assume no interactions with humans. The first step provides a more realistic condition in being less flexible, highly rigid, but generally more resilient to the environmental changes. This expands the working range of systems’ acceptable conditions to higher thresholds. The second step allows the system to work far better than when heavily restricted by living creatures. The third allows us to study systems’ behaviour more precisely upon a better-defined application-specific set of assumptions.

The rest of this paper is organised as following. Section 2 provides a brief for the networking aspects of the SEE applications whilst Section 3 looks into the synchronization issues of the system. Section 4 analyses the problem of spectrum sharing and interfering issues in space followed by Section 5 to examine the energy issues of SEE including medium access control as a way to reduce the use of scarce energy resources. Finally, Section 6 provides collective briefs on typical examples leading to six groups of SEE based on the application scenarios and their working environments.

II. WIRELESS NETWORKING FOR SEE

Ever-larger numbers of people are relying on the technology directly or indirectly as it enables the deployment of networks of densely distributed sensors and actuators for a wide range of environmental applications encompassing a variety of data types including acoustic, image and various chemical and physical properties. Wireless sensor network topology may be divided into 3 topologies: Star Topology, Cluster Tree Topology and Mesh Topology. The remote configuration of the sensing node should ensure that it should continuously transmit digital sensor data to other coordinators located in the nearby area. For wider applications especially in SEE, the networking should be smart, efficient and also it should be a low-cost, low-power system. The low cost allows the technology to be widely deployed in wireless control and monitoring applications and the low power-usage allows longer life with smaller batteries. The mesh networking is usually the preferred choice as it provides high reliability and a larger range.

The network routing is a basic element of closed-loop, real-time sensing and control and its implementation is challenging due to dynamic, uncertain link or path delays. The delays lead to instability, estimation error and low data delivery in the performance of the system. A multi-timescale adaptation (MTA) routing protocol has been proposed in [11] taking into consideration multi-timescale estimation (MTE) based on accurately estimating means and variance per packet transmission time. The architecture of MTA-based real-time routing is depicted in Figure 1. It is important to emphasize that the packet dispatcher is using time synchronization and delay estimation techniques in order to adapt the networking layer to the environmental conditions.

The challenges related to time synchronization will be discussed in the next Section. However, at this point it is worth noting the intentional closed-loop available between data and the control plane in MTA protocol enabling the reinforcement of real network performance metrics into the control plane in order to re-adapt the networking layer to perform well in extreme conditions in which either packet delays are being unusual or time synchronization is being affected.

Distributed radar sensor networks (RSN) grouped together in an intelligent cluster headwork on ad hoc fashion provide spatial resilience for target detection and tracking [12]. The RSN may be used in EE such as tactical combat systems that are deployed on airborne, surface, and subsurface unmanned vehicles in order to protect critical infrastructure from terrorist activities. An orthogonal constant frequency (CF) pulse waveform model has been proposed which eliminates interference between radar sensors. A distributed estimation and control approach for WSAN has been proposed accounting for noisy condition as well as packet loss and it shows that the mean and variance of estimation errors are bounded [13]. One of the challenging issues for integration of wireless sensor networks and radio-frequency identification systems is the low efficiency of communication due to redundant data. The five-layer system architecture along with a data-cleaning algorithm proposed to achieve synergistic performance [14]. The developed
algorithm can eliminate redundant data effectively and thereby save energy of data communication and avoids time delay. The coverage of sensing area becomes dynamic if there is a continuous movement of sensors. Dynamic area coverage and intrusion detection capability of a mobile sensor network has been reported in [15]. Delay synchronization, elimination of redundant data and dynamic sensing areas are some of the critical routing challenges that WSN needs to address when deployed in SEE. In this context, Xue et al. [16] have proposed a velocity-based routing protocol with a reliability and energy-efficiency routing scheme to enhance the network real-time routing performance, energy efficiency and transmission reliability. The proposed method has made use of some intelligent functions including (a) selection of an eligible relay node using two-hop neighborhood information, (b) estimated delivery velocity and (c) energy-aware-based energy-cost.

An unstructured multi-hop radio network model, with asynchronous wake-up, no collision detection and little knowledge on the network topology, has been proposed for capturing the harsh characteristics of initially deployed wireless ad hoc and sensor networks [17]. The issue of a local broadcasting problem has been dealt with by adopting the physical interference model and without any knowledge of the neighborhood to obtain a new randomized distributed approximation algorithm. This scenario proposed in [17] deals efficiently in environments in which there is a high degree of uncertainty, which is an inherited feature of SEE.

The conventional WSN consisting of a large number of heterogeneous sensors deployed over a wide, unstructured, harsh and time-varying environment presents various interesting problems. A system of tracking mobile robots and mapping an unstructured environment, using 25 wireless sensor nodes in an indoor setting environment has been reported [18]. The sensor nodes are deployed into an unknown environment. Three sensor nodes known as anchor nodes are mounted in a triangle frame, and two nodes are mounted on two of the mobile robots. The sensor nodes form an ad hoc network of beacons and localize themselves with respect to the anchor nodes using the pairwise ranging data. The localized sensor nodes are then used to track the locations of the mobile robots in the field [18]. In WSN, there are possibilities of attacks from inside the network by malicious and non-cooperative selfish nodes or by any unwanted outside nodes. A ubiquitous and robust access control (URSA) solution for mobile ad hoc networks has been presented in [19]. It uses tickets to identify and grant network access to well-behaving nodes and thus effectively enforces access control in the highly dynamic, mobile ad hoc network. Using a handheld computing device with wireless access to have anytime, anywhere access to the latest factory floor information has been proposed [20]. These authors have designed and implemented an energy-efficient and intrusion-resilient authentication (ERA) protocol, which can achieve security self-recovery when strong adversaries compromise either a user’s handheld device or a factory authentication server to obtain the authentication secrets. Implementation of a low-cost, data access-efficient, sample and easy to deploy, waterproof, and heatproof outdoor cable access point (CAP) device for ubiquitous network applications has been presented in [21]. The whole purpose of the CAP device is to effectively extend the coverage of the outdoor wireless access link and to further provide a data access-efficient service for construction of a ubiquitous networking environment in the metropolitan area.

A movement-aware vertical (MAV) handover algorithm between WLAN and mobile WiMAX for seamless ubiquitous access has been addressed in [22]. The purpose of the development of the algorithm is to exploit the movement pattern to avoid unnecessary handovers in the integrated WLAN and mobile WiMAX networks. Sometimes, it is quite difficult to extract accurate information from raw sensors data and feature extraction techniques become quite useful for this situation. A novel feature extraction technique based on a nonlinear manifold learning algorithm for autonomous navigation systems has been reported in [23]. Transmitting the wireless data in the presence of extreme dense environments poses the question of how to exploit wireless networks more efficiently. This efficient management of handovers works well in SEE scenarios where it is critical to have a constant monitoring of variables, for example, due to human exposure hazards, and it requires soft handover techniques for continuing the session along different wireless technologies.

III. SYNCHRONIZATION AND COOPERATIVE TECHNIQUES

While the previous Section provides a brief review of different robust networking protocols, this Section examines on different challenges that appear explicitly under extreme environments and are directly related to the management of the wireless network and the synchronization and cooperative collaboration of the nodes.

The idea is to provide the reader practical examples based on real deployments to appreciate the possibility of such local solutions and a better understanding of the network operational management under SEE conditions.

A. Time Synchronization

One of the critical aspects associated to distributed sensing is the imperative necessity of performing an accurate time synchronization between all the involved nodes of the network in order to associate the sensed data with the time in which such data was sensed in order to aggregate and correlate the data gathered to be distributed by the different nodes. A simple error in the time synchronization will not only lead to non-accurate data but also a severe case will invalidate the complete series of data along the sensed period. Almost all the current wireless sensor nodes used in the vast majority of the real deployments carried out so far are using time measurement instruments, which are very sensible to errors when they are exposed to slight variations in the environmental conditions. So, environmental monitoring of specific geographical areas considered SEE is a representative example of the application to be analysed as an example of WSN deployment associated to extreme working conditions. This environment monitoring is directly associated to some scenarios in which WSNs are deployed with the intention of monitoring extreme temperatures such as volcano monitoring.
glacier monitoring, nuclear-plan thermal monitoring, industrial monitoring, thermal monitoring of chemical products and aerospace thermal monitoring. These scenarios usually use such synchronization twofold: a) To enable the efficient correlation between the metrics gathered distributed by all the nodes; b) To perform an efficient energy management of the WSN in order to prolong the lifetime. These are some well-known time synchronization protocols for WSN like reference broadcast synchronization (RBS) [24], timing-sync protocol for sensor network (TPSN) [25] and flooding time synchronization protocol (FTSP) [26], to name a few. All these protocols heavily rely on the usage of crystal oscillators where the actual frequency of oscillation depends on many factors such as the type and the cut of the crystal, capacitance, and specially temperature. Figure 2 shows two sensors, the first one is exposed to a constant temperature while the second one is exposed to a range of temperatures (−40° to +40°) in steps of 10°. It is also representing the time synchronization error to see how this error is directly related to the temperature due to the crystal oscillator used. As the reader can see in Figure 2, the variance in the temperature lead to a significant increase in time synchronization errors, this fact emphasizes the clear need of using alternative time measurement instruments for deployments in SEE or at least trying to minimize the variance of the interference by means of isolation techniques, correction techniques, redundancy techniques, etc.

Another approach to achieve efficient time synchronization is provided by Raskovic et al [27]. They have provided the sliding clock synchronization (SCS) protocol suitable for time synchronization under extreme temperatures. The key aspect of this protocol resided in the inclusion of special nodes called central node sending periodically time synchronization beacons. Then, the node measures the time between two consecutive beacons as well the time measured locally. They also periodically measure the echo time to determine the time it takes a message of fixed size to reach the central node and to be returned back. The calculated ratios gathered from all these measures are averaged enabling the identification of the differences in crystal frequencies to be taken into account. This cooperation between nodes results in SCS offering a significant reduction of the error rate when sensors are exposed to high temperatures, thus providing a better network operational management. Table 1 shows the comparison between the different protocols analysed.

Another example is sensing underwater using wireless sensing which is also a very challenging scenario associated to extreme conditions due to the intrinsic nature of the medium in which high frequency (HF) radio waves are strongly attenuated. Traditional radio modules operating in MHz and GHz cannot be used underwater which is an acoustic-based and optical-based communication therefore the emerging technologies cannot work for these scenarios. Martinez and Hart [28] proposes a way for understanding of sub glacial processes, especially to investigate their links with climate change, as well as developing the next generations of environmental sensor networks. They perform the real deployment of sensors for the monitoring of glaciers in the arctic by means of the deployment of 30 nodes in valley glaciers in Briksdalsbreen, Norway and 8 nodes in Skalafellsjökull, Iceland between 2003 and 2006. A diagram of the deployment undertaken is depicted in Figure 3.

The base station is located outside the water with the transceiver placed into the water and the rest of the sensors are in the water. The main geological objectives are to provide a long term record of water pressure changes in the ice and sub glacial sediment to enable the investigation of the relationship between water pressure, till strength and till temperature in order to understand till sedimentation. Operational conditions are between −40° and +20° and a lifetime of four years must be ensured. The sampling rate of the sensors is fixed at once per four hours, partly because changes are expected to be slow but also to save power. Long radio-disconnection periods are

| Table I: Comparison of SCS Errors [27] with Other Synchronization Algorithms |
|-----------------|-----------------|-----------------|-----------------|
|                 | TPSN [7.37 MHz] | FTSP [7.37 MHz] | SCS [4 MHz]    |
| Average         | 1.85μs          | 0.5μs           | 0.32μs         |
| Worst Case      | 4.41μs          | 2.3μs           | 3.25μs         |
expected but glaciologists wanted every data sample, even if this data is delivered months later. So, a large ring buffer (6,000 readings) for the data is used in each node in order to store data for up to a year. The sensing platform acts as remote sensing architecture in which all the monitored information is stored in the internal memory.

A GPS device is attached to the base station and a broadcasting of the GPS time to all motes is done daily as a way to keep synchronization within seconds and save power by narrowing safety margins on wake-up scheduling. Power management is a key to satisfying the requirement for long-term system life. Since a daily data transfer is acceptable, the radios on every unit are completely off most of the time and limited time windows are given to those tasks that used them. After several trials, the authors decided to insert the transceiver of the base station into the water because otherwise the loss of signal is significant and it is impossible to establish connections so far at 20 meters (testing several frequencies such as 868 MHz, 433 MHz, 172 MHz). This transceiver is standardized around the Radiometrix BiM unit tuned to 173.25 MHz but powered at 100mW rather than the default 10mW. The key cooperative aspect of this deployment is the usage of a well-known windows time frame in order to perform the daily coordination and synchronization between all the nodes in order to increase significantly the lifetime of the network and to reduce the usage of communication links.

B. Fault-Tolerance of Sensing Nodes

Another good example of cooperative technique directly associated with SEE is proposed by Wenning et al [29] with the environmental monitoring aware (EMA) protocol which takes into account the realistic fact that a deployment of a WSN in extreme conditions such as forest fire scenarios which can destroy the sensors devices in any moment due to the fire. This fact has direct implications for the network lifetime, performance and robustness. They focused on node failures caused by the sensed phenomenon itself proposing a resilient method aware of node destruction being able to adapt the network topology accordingly before node failure results in broken routes, delay and power consuming recovery actions. EMA uses as routing criteria different key metrics: a) health status; b) received signal strength indicator (RSSI); and c) hop count. The key aspect in this deployment is the health status defined to be a value between 0 and 100. 0 indicates the worst and 100 the best health. If the temperature of the node is below a lower threshold then the health status is 100. Then, the health status is being decreased using a directly proportional relationship between temperature and health status. The upper threshold is setup in a temperature in which the node is likely to fail within a very short period of time. Then, nodes identified in bad health status condition can initiate a self-healing recovery method for the sensed data and also for the network topology improving the operational management of the network.

Another critical aspect in space missions and SEE conditions is to enable sensor nodes to take over the damaged functions of their neighbor sensor nodes automatically. This collaborative approach ends up with a high reliable WSN that never stops monitoring even in extreme conditions and does not require maintenance if some sensor nodes suddenly die. Figure 4 shows a WSN with some nodes performing different functions. A different coloured node represents different functions, for example, sensing functions. The links are routes established using any of the dynamic routing protocols already available. Then, when a node dies, Miyazaki et al [30] proposes a protocol for enabling other nodes to take over the function being carried out of the dead node.

Miyazaki et al [30] proposed an architecture in which each node has a table, named a neighbor management table (NMT) that manages the status of the functions of its neighborhood. This table has an entry per each different neighbor function. Each entry has an associated timestamp. A ‘notice list’ the list of nodes that can take over the function being carried out by this node. Then, the protocol sends periodically broadcast HELLO packets to their neighbor (not flooded) as any routing protocol does in order to notify its existence to its neighbors. This HELLO packet has the list of functions that this node can take over. When a timeout is expired and no new HELLOs are received or HELLOs are received with fewer functions, this node has died or some functions have been damaged. If a node detects such function damage it can take over the function, the node floods a NOTICE packet to notify other nodes that it is a candidate for the damaged function alternative. The NOTICE packet contains the ID of the die node and a value indicating the node suitability to assume such an alternation function. This value is calculated for balancing energy and the distribution of sensor functions. After waiting for NOTICE packets from neighbor nodes for a threshold time, the node with best suitable value floods a TAKEOVER packet to all of the nodes to inform them that the alternation function has been executed. This simple cooperative method improves significantly the reliability and resilience of the WSN, which is especially welcome for space missions and scenarios in extreme conditions where WSN needs to be at the highest level of reliability.

C. Network Management for SEE

An important aspect of network management related to the usage of WSN in extreme conditions is generally the difficulty associated to the deployment of the sensors in the
sense field. Once the WSN is deployed, it is highly difficult to remove the sensors from the field, especially in SEE. So, these sensors need to be provided with reconfigurable and re-programmable processing techniques enabling the decoupling of the sensing infrastructure from the applications running on top of it. Deluge [31] provides a reliable dissemination protocol for distributing a large amount of data through WSN. It uses full image replacement strategy for updating all sensor nodes. So, as soon as the whole image-data received by the sensor nodes the network starts the update procedure to replace the old image by this new one. Scenarios in extreme conditions demands different design principles in which data transmission is minimized due to the hard network conditions and also in which recovery mechanisms are considered a critical part of the protocol just in case the updating process of the nodes ends up in failure due to the extreme conditions. The former can be tackled using two-stage differential update, Diff [32]. In essence, both the old and new version of images are compared on a host machine sending only the different components or contents to all sensor nodes for updating. The latter addressed by Lien and Chiang [33], who have also provided a recovery mechanism for the reprogramming of WSNs. The main design principles for this recovery technique are: a) It must have as much data retransmission as possible; b) Recovery process must be performed locally in sensor nodes to minimize the communication. The main approach presented by Lien and Chiang is depicted in Figure 5.

The figure shows several volumes located in the ‘external flash device’. The authors use four backup volumes for the updating process. The first backup volume is used to receive a patch file sent from the host machine (see signal point 1 in Figure 5). After the sensor node finishes receiving patch file, it will copy the file into another backup volume according to the current backup pointer (see signal point 2 in Figure 5). The backup pointer always points to the next volume address for receiving a new patch file. Since there are total three backup volumes to store three versions of patch files (the first one is used to store received file), the backup pointer must rollback to the first backup volume address for starting the next backup cycle. After three incremental updates, the fourth will rollback the pointer address back to the first backup volume. Then, the reprogramming flag is set and writes the backup pointer address into EEPROM (see signal point 3 in Figure 5). Sensor node will later reboot and start to execute the boot loader for reprogramming. The boot loader will perform the Two-Stage Diff update mechanism according to the patch file. If any error occurs during the reprogramming, the authors proposed that incremental recovery mechanisms would be executed to recover the failed sensor node. These incremental recovery mechanisms start from setting a recovery flag and write the flag into EEPROM. A sensor node will later reboot and perform the recovery mechanism according to the recovery flags. If any error occurs during diff-based reprogramming, the recovery mechanism will set version N recovery flag. After rebooting, the boot loader checks N recovery flag and performs the recovery mechanism. First, it will load the oldest fully executable image from external flash into program flash (see signal point 4 in Figure 5).

According to how many patch file versions are stored, the mechanism will perform incremental recovery by patching the old full image many times until the current version. If the N recovery mechanism fails, the N-1 recovery mechanism is performed (see signal points 5 and 6 in Figure 5). It ensures that at least the node can rollback to the previous version which has been previously functional in the past in order to be able to replace the corrupted image with a more appropriate one.

IV. DYNAMIC SPECTRUM SHARING IN SPACE AND EXTREME ENVIRONMENTS

A. Motivation

There seem to be far less wireless devices in space than on earth, but it is expected that there will be a need in orders of magnitude for more wireless sensors in space than those we have on earth today. This calls for robust and reliable dynamic spectrum sharing schemes in space and of course this applies to other extreme environments. Since there is no federal communication commission (FCC), nor any action from the international telecommunications union (ITU) to regulate the spectrum in space, the sharing issue would be even more critical than it is in terrestrial systems. Noting that safety, security, and reliability of space habitats is dependent on wireless sensors, the importance of studying spectrum sharing in space becomes more evident. That is, we need smart structures that can withstand harsh space conditions and still have modes of failure prone to micrometeoroids and space debris impacts. Wireless sensing systems such as:

- Structural integrity and shape monitoring sensors
- Leak detection and localization sensing systems
- Impact detection and localization sensor networks

are just a few examples of wireless sensor systems that will be installed in space habitats and space vehicles. There wireless sensors in close proximity to each other need to operate in harmony on a limited frequency spectrum in concert with various others on board radios and wireless communications systems for surface and deep space networks.

Spectrum sensing enables efficient sharing of this scarce resource. Although a spectrum may seem plenty in space, due to the aforementioned arguments, the large number of users makes the sharing problem too challenging to handle.
Extreme environments in their own terms need to deal with the problem of spectrum sharing. Due to limitations caused by environmental conditions such as extremely high or low temperatures, or harsh chemical vapours present in the vicinity of sensors, special types of material needs to be used in sensors design. For instance, UMaine’s new start-up company, Environetix is developing high temperature wireless sensors that can withstand above 1000 degrees Centigrade inside jet engines [34]. The material than enables operations in such environments but works at specific frequency bands, limiting spectrum access even further.

This Section includes a review of wireless sensors without batteries that can withstand harsh space and extreme environments, modelling the interference in a network of wireless sensors, interference mitigation solutions for SEE, and a comprehensive review of spectrum sharing with sensing errors in SEE.

B. Wireless Sensors for Space and Extreme Environments

Batteries are the most limiting factor in the operation of wireless sensors systems for SEE. On board battery power can be saved with implementation of multi-state operation such as off, sleep, or standby power states, lowering the operating voltage, precision hardware control, and power efficient use of the wireless spectrum [35]. Scaled down modulation schemes can be used to save power as well [36]. Alternatively, minimizing overhead in sensor data packets based on properties of the sensor data can also help overcome the limited battery on board [37].

The battery power saving is the least of our concerns in extreme environments where even having a battery, due to harsh environmental conditions, is questionable. That is why passive or battery-free wireless sensors can be very attractive for using in these environments. Weight and cost savings is another reason that makes passive sensors a good choice in space applications.

One example of using battery-free sensors in space applications is monitoring temperature at several points on the mirrors of the space telescope (Figure 6). For a fine-resolution imagery we require an array of small mirrors to remain focused and keep their structural integrity. The harsh space environment with high dynamic range of the temperature causes the mirrors to expand and shrink. Using battery-free wireless sensors can enable temperature correction by turning localized heaters on and off as needed. The problem of spectrum sharing becomes an issue as the number of sensors grows.

Another example is embedding sensors in the heat shield of re-entry vehicles including inflatable decelerators (Figure 7). Extremely high temperatures at the re-entry need to be tolerated by the wireless sensors for their effective operation. Any unusual, locally high temperature outside of the normal window can be detected and catastrophic conditions may be avoided by directing cooling liquid to those specific locations.

Passive wireless sensors may be realized using multiple technology platforms such as semiconductor based sensors, piezoelectric substrates, and inductive sensors. Surface acoustic wave (SAW) based sensors are one of the widely used technologies that are based on concentration of the travelling wave on the surface of the piezoelectric based sensors [38]. Prior implementations of SAW devices were for one sensor operation at a time. Recently, a coded SAW sensor system was proposed in [39], where a multiple-access feature was added using coded sensors.

C. Interference Problem in Dense Wireless Sensors Networks Deployed in SEE

The large number of wireless sensors deployed in space habitats and vehicles creates an interesting and challenging scenario under the general spectrum-sharing problem. The interference created by adjacent sensors when one particular sensor being read by an interrogator. Various techniques such as time, code, and frequency diversity may be used to address this issue to some extent. The model below is based on the results presented in [40].

Let us assume functions $M(.)$ and $N(.)$ refer to matching (autocorrelation) and non-matching (cross-correlation) responses from desired and interfering sensors, respectively. Denoting each orthogonal code in a network of $n$ sensors with $C_j, j = 1, \ldots, n$, the received response at the interrogator can be formulated as,

$$R_1 = M(C_i) + \sum_{j=1, j \neq i}^{n} N(C_j)$$  (1)
In order to find the average interference caused by one or two sensors not knowing which sensor is interfering at each time slot, the following equations may be used:

\[
f_1 = M(C_i) + \frac{1}{n} \sum_{j=1, j \neq i}^{n} N(C_j) \tag{2}
\]

\[
f_2 = M(C_i) + \frac{1}{n^2} \sum_{j=1}^{n} \sum_{k=1}^{n} N(C_j) + N(C_k) \tag{3}
\]

These equations can be generalized to include \( m \) interfering sensors.

\[
f_m = M(C_i) + \frac{1}{n^m} \sum_{j_1}^{n} \cdots \sum_{j_m}^{n} N(C_{j_1}) + \cdots + N(C_{j_m}) \tag{4}
\]

A reduced complexity method for calculating the approximate value of (5) for a large wireless network is proposed in [41]. As seen in Figure 8, peaks of the signal are much easier to detect after interference mitigation is applied to the aggregate response.

**D. Dynamic Spectrum Sharing With Sensing Errors**

A totally different form of interference in spectrum sharing literature is called, primary-secondary interference. The main idea dates back to Simon Haykin’s original paper introducing cognitive radio [42] where the operation of secondary users (un-licensed) while primary users (licensed) are silent is permitted. This is subject to interference mitigation methods to make sure primary users who paid for the licenses spectrum do not get harmed by ad hoc secondary users.

This elegant scheme has not been widely used yet, since errors in spectrum sensing are unavoidable and there is no incentive for primary users to allow access to secondary users. Recently, a reputation-based Stackelberg game approach for spectrum sharing is proposed [43]. In this work, concept of cognitive cooperation is introduced, where secondary users act as relays for primary users to help them when their main channel and has low quality providing more spectrum holes in future time slots. The price to pay for possible interference is relaying. Time allocation to various phases of transmission (primary only, secondary relay for primary and secondary only) has been optimized keeping fairness in the network. See Figure 9.

The problem of spectrum sharing in SEE in the context of wireless sensor networking are few in the literature with much more remaining as future research directions. The interference in passive sensors versus interference concept in cognitive radio networks mentioned above is also for future research where the combination of these two concepts and cognitive interrogation systems for passive networks should be studied.

**V. ENERGY CHALLENGES AND ENERGY EFFICIENT MULTIPLE ACCESS**

Reliable and efficient multiple access remains a significant research problem for mission-critical applications in SEE.
characterised by challenging and highly dynamic environmental conditions [44]. It is well known that medium access control (MAC) plays a crucial role in providing high channel utilisation efficiency, low delay and energy-efficient communication in wireless networks. Outages due to energy shortages and adverse propagation conditions are significant problems in SEE, calling for highly adaptable and energy-efficient MAC protocols. Sensing systems designed for operation in space or underwater face additional challenges, notably long and potentially variable propagation delays, which severely inhibit the throughput capability and delay performance of conventional MAC schemes. This Section reviews some of the challenges associated with reliable and efficient multiple access in SEE, focusing on underwater sensing systems.

A number of multiple access schemes have been proposed for resource constrained wireless sensor networks [45]. Emphasis has often been placed on energy-efficiency, based upon the use of battery powered sensing nodes, which permit flexible deployment, typically outdoors and in potentially remote and/or inaccessible locations. Efficient duty cycling and the use of low power sleep modes are commonly employed at the MAC layer [46]. Although such approaches extend the lifetime of wireless sensing systems, nodes will ultimately fail without some form of ambient energy harvesting technology. This is, of course, a critical issue in SEE environments where battery replacement may not be feasible. Informative surveys of the possibilities, technologies and challenges associated with ambient energy harvesting for wireless sensor networks can be found in [47] and [48]. Solar, mechanical and thermal are the most promising energy sources but their availability is heavily environment dependent and the physical size of typical sensing devices is a significant constraint. Attempts have been made to produce optimal sleep and wakeup schedules based upon the assumption of fixed recharge rates from energy harvesting devices [49]. Although such optimisation methodologies have merit, the amount of energy generated from a harvesting device is heavily dependent on ambient conditions. The time varying availability of energy needs to be considered to avoid outages, and if batteries are used, their recharge characteristics need to be accounted for. Other forms of energy storage may be beneficially employed, such as super-capacitors [50]. A good comparison of the characteristics of super-capacitors in comparison to Li-ion batteries and hybrid devices can be found in [51]. Table 2 summarises some of the key characteristics. It is worth noting that super-capacitor charging characteristics are particularly suitable for long term use in extreme environments, since they can operate at more extreme temperatures, offer much lower charge times and a greater number of charge cycles. They are significantly more expensive but the amount of energy available will, however, be significantly reduced.

A new approach to power management is required to effectively support harvesting technology, which is geared towards using energy at the rate at which it can be harvested, with network protocols and functionality governed by this rate. This has been termed energy-neutral operation and it would ultimately support perennial operation [52]. The use of energy harvesting technology has important implications for medium access, since uncertainty surrounding the future availability of energy makes it difficult to arrange reliable duty-cycles, transmission/reception schedules or back-off times in the traditional way. Energy shortages may occur at critical times, for example when a node is scheduled for a period of activity. It may be counter-productive to wait, and decisions to transmit or to be available for reception may be better taken when sufficient energy is known to be available. A number of recent papers are devoted to evaluating the performance of existing MAC protocols with energy harvesting models. The impact of discontinuous energy availability on the performance of traditional time division multiple access (TDMA) and framed ALOHA schemes is investigated in [53] for a single hop wireless sensor network. Results show that the asymptotic packet delivery probability and time-efficiency (which relates to the achievable channel utilisation) of all the schemes is heavily dependent on the energy-harvesting rate. Unslotted carrier sense multiple Access (CSMA) has been shown to be more efficient than a slotted variant for a number of reasons [54]. The energy used for slot synchronisation calls for longer energy harvesting periods, which reduces transmission time (and potential throughput) on the channel. Energy overheads for sensing are lower in the unslotted scheme because a node can immediately enter a recharging state when a channel is sensed busy. In the same paper, a probabilistic polling scheme is proposed which adapts a contention (transmission) probability based on the energy harvesting rates. The throughput performance of the S-MAC protocol has been evaluated for an energy harvesting based WSN in [55]. An important trade-off in between throughput and remaining energy in the battery is shown. Based on minimum thresholds for these parameters, suitable bounds for the duty cycle can be determined to meet the quality of service and network lifetime requirements. New approaches are starting to emerge such as RF-MAC where energy is harvested through directed radio frequency waves [56]. RF-MAC is designed to effectively manage the transfer of data and energy in the same band. It is shown to offer an improvement in network throughput over a modified unslotted CSMA based scheme.

The challenges associated with long propagation delays are well understood for satellite systems. Demand Assignment Multiple Access (DAMA) is commonly employed as a means of achieving high channel utilisation efficiency, since capacity can be allocated to nodes in response to time-varying requirements. Many approaches are however limited to a minimum end-to-end delay bound of two/three hops for on-board and ground based schedulers respectively.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional Supercapacitor</th>
<th>Hybrid Supercapacitor</th>
<th>Li-ion battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle life</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Charge time</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Energy density</td>
<td>2 to 6 WH/Kg</td>
<td>10 to 50 WH/Kg</td>
<td>120 to 200 WH/Kg</td>
</tr>
<tr>
<td>Power density</td>
<td>1 to 10 KW/Kg</td>
<td>1 to 5 KW/Kg</td>
<td>0.1 to 1 KW/Kg</td>
</tr>
</tbody>
</table>
corresponding to $\sim 0.5s-0.75s$ for geostationary satellite systems. Underwater communication systems are often based on the transmission of acoustic waves, since electromagnetic waves suffer high levels of attenuation and only propagate over very short distances. The substantially lower propagation speed of acoustic waves ($\sim 1500m/s$) introduces comparable delays to geostationary satellite systems with significant variation in delay if transmitters are located at different distances from a common receiver. The underwater propagation environment is particularly complex and MAC protocols remain a significant research challenge underwater [57]. The remainder of this Section is therefore devoted to discussing the primary issues and potential solutions.

Underwater hardware development and sea installation is very expensive and commercial acoustic modems are only able to provide modest data throughput in networks. As a result, current deployments comprise low numbers of instruments recording data during a mission for later retrieval. A breakthrough in multiple access capability is required to fully exploit the exploration, sensing and monitoring capability that networks of mobile nodes can provide, yet most research in underwater acoustic communication deals with the physical layer. Existing multiple access techniques struggle to address the fundamental constraints, including long and variable propagation delays, the complicated space variability of the channel (e.g. shadow zones due to refraction), extensive multipath phenomena, and the fast time-variability of the channel, especially for mobile nodes.

A wide range of conventional MAC techniques have been considered for underwater networks and Table 3 summarises the primary advantages and disadvantages of alternative approaches. Power control is required to combat the near-far problem, challenging in an underwater environment given the rapidly varying channel conditions and long propagation delay. Provision of links with fixed bandwidth and data rate make FDMA and CDMA highly inflexible. Some form of adaptive TDMA is a natural solution for packet-switched communication but schedule-based schemes suffer from long reservation delays, restricting their ability to adapt to changing traffic requirements and propagation conditions. They also incur significant signalling and synchronisation overheads. Contention protocols based on CSMA can provide more rapid and flexible access to the communications medium, but the effectiveness of physical carrier sensing is significantly reduced with acoustic propagation, due to the highly variable propagation delays. Handshaking methods based on the principles of floor acquisition multiple access (FAMA) and multiple access with collision avoidance (MACA) have been extensively exploited to alleviate the hidden terminal problem [58], [59], akin to schedule-based schemes, but the time taken to exchange control packets prior to data transmission introduces notable delay and overheads at acoustic propagation speeds. ALOHA schemes represent a logical approach, but the absence of any form of coordination renders their throughput capability poor. Recent work to address such constraints has demonstrated the benefits of applying a stochastic transmission strategy to ALOHA, based on heuristic objective functions [60]. It has been argued that no single MAC protocol is able to satisfy the diverse requirements associated with underwater acoustic networks and that adaptation based on a suite of protocols is more appropriate [61].

The development of efficient MAC protocols for underwater sensing systems is severely inhibited by the absence of suitable models for signal propagation. Virtual signal transmission recently developed and proposed in [62] is a significant step towards such a model, but it requires significant computation time and can only be used for relatively short signal transmission sessions. In [63], a different approach is proposed using waymarks over the trajectory of moving communication nodes. Based on local spline approximation of the time and space varying channel impulse response, this model allows simulation of infinitely long communication sessions. Crucially, it has the potential for real-time hardware implementation. Accurate models of underwater signal propagation need to be developed in order to provide the understanding required to design effective MAC protocols for such environments, especially for mobile systems in arbitrary acoustic environments.

The success and adoption of terrestrial radio systems is largely due to global standardisation efforts and the development of integrated physical (PHY) and MAC layer standards. The current treatment of the MAC layer in relative isolation is another significant issue. The variety of scenarios where underwater communication networks can be used dictates the need for the design of a universal PHY capable of adapting to different conditions [64], [65]. The most promising modulation schemes for underwater acoustic communications are considered to be schemes based on multicarrier modulation, such as OFDM and SC-FDMA. Drawbacks of such schemes include their sensitivity to the Doppler effect due to node movement and low spectral efficiency due to long guard intervals. However, as recently shown [66], these issues can be efficiently addressed. The development of a universal PHY
layer in tandem with the MAC layer is now required, to enable intelligent and adaptive use of optimised channel sets in frequency and time as a means of providing flexible allocation of resources combined with time and frequency diversity.

VI. Typical SEE Application Cases

This Section provides listing of recent WSS-SEE solutions that can be categorised as the application paradigm of the WSS-SEE platform and associated services that could benefit by adopting the UWS approach. Upon their specific features and their potential for promoting we assign them into correct groups in their ‘typical example’ column of a new table. However, due to the complex nature of some systems there could be some overlaps. Adopting UWS approach under the flagships of WSS-SEE would accelerate the application-based process. As a starting point we divide them into six different groups. Each of these groups incorporates its own specific characteristics for viable applications depending on the type of EE for unconventional working condition as follows:

1) Group 1 represents those free from terrestrial dominating factors (space).
2) Group 2 represents those immersed or controlled by liquids usually water’s dominating factors (underwater) – they can be extended to any size from a small container to large water-farming or aquaculture lake.
3) Group 3 represents those buried in covering materials as their main performance is limiting factors such as the ground where they have the problem of communicating with each other or systems outside the soil. Deep mines, body-implants, and many agricultural applications are included in this group.
4) Group 4 represents those loosely confined to a restricted area so that their performance is controlled by specific enclosed dominating factors when indoors – a wide range of applications such as systems working inside tunnels, subways, block buildings, and caves fall into this group.
5) Group 5 represents sensors on the move, also called mobile sensor systems (MSS).
6) Group 6 covers all remaining sensing cases working under special and specific environments such as energy sensitive systems, data sensitive and harsh Antarctica, arid, mountains and desert, volcanoes, etc.

Table 4 highlights six environmental groups divided consequently into a few application areas upon their working conditions, supported by typical examples from the literature.

Table 4: UWS Approach Development Grouping of Sensor System Unconventional EE Working Environments. Each is Accompanied by Associated Application Areas

<table>
<thead>
<tr>
<th>Env. Group</th>
<th>Appls. Area</th>
<th>Typical Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 /Space</td>
<td>Observation /Discovery /Interactive</td>
<td>-eg: Europa Mission [67], Sensors in Solar Space Missions [68], Advantages of using Integrated Wireless Sensing in Spacecraft Monitoring and Tracking [69] &amp; [70], RFMS: The Environmental Sensor Suite for the Mars Science Laboratory Rover [71], Distributed Space Satellite Sensor Networks [72], Distributed Intelligent Robotic [73], Space and Solar-System Missions [68]</td>
</tr>
<tr>
<td>2 /Underwater</td>
<td>Monitoring /Discovery</td>
<td>-eg: Underwater Acoustic Networks [58], Coordinating Submerged Sensors for Distance Measurement and Localization Avoiding Acoustic Multipath Fading [6], Adaptive Error-Correction Coding and Modulation for UWA [65] &amp; [64], Fast-Varying Acoustic Channels and Selectivity [66] &amp; [63], Hidden Terminal Delay Problems [59], Underwater Wireless Sensing for Autonomous Underwater Vehicles (AUV) [46], Platform Dynamics and Emerging Technologies [74] [61] [62]</td>
</tr>
<tr>
<td>3 /Ground/Barred</td>
<td>Agric, Mining</td>
<td>-eg: Magnetic Induction Through Soil [7], Under 1 GHz Wireless Soil Propagation Properties [76], Extreme Path Loss and Other WUSN Research Challenges [77]</td>
</tr>
<tr>
<td>4 /Confined</td>
<td>Navigation/cls, Clinicall</td>
<td>-eg: Dynamic Localization of Moving Robots [80], Localization using Sensor Radars [81], Acoustic Sensor Networks Distributed Node Tracking [82]</td>
</tr>
<tr>
<td>5 /Industrial</td>
<td>Robotics, SIEM</td>
<td>-eg: Real-Time Manufacturing Tracking and Monitoring [87] &amp; [88], Railroad Alarm Monitoring [89], Robotic Rapidly Changing Env. [90]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-eg: Terrestrial Pipe Protection [97] &amp; [98], Desert Dust Devils Wireless Motes Measuring Temperature, Pressure, Humidity and Acceleration [99] &amp; [100].</td>
</tr>
</tbody>
</table>
Networking many similar wireless sensors in space could be used for many applications such as sustainable monitoring of properties such as weather, chemical, physical, and atmospheric sensing of the soils and surfaces of other planets using more economical space based networks (SBWSN), applying the terrestrial concept to space [68].

Spacecraft monitoring and tracking associated industries such as space surveillance networking (SSN) are still premature. They can help to detect and track all new and existing detectable space objects, predict and characterize orbital movements for sensitive information such as country of origin, mission, alert or launch for any required activities [69], [70].

Over the period of the mission, the mars science laboratory (MSL) the REMS station requires to investigate habitability factors on a Martian surface, mainly environmental temperatures, UV radiations, and water recycling system. Therefore, REMS sensors will record temperatures of the air and ground, measure the wind flows in various directions, pressure, and humidity, as well as ultraviolet radiations [71].

Plasma bubbles caused by ionospheric plasma depletions occur at low latitudes after local sunset with bubbles as large as thousands of kilometers propagating at speeds up to hundreds of meters per second which may create unknown instabilities in low orbit systems. In order to investigate these we can use a special distributed space sensor (ionospheric multiple plasma sensor networks) of small systematically scattered sensing objects employed in two stages of (a) to set around spatial monitoring of plasma bubbles and (b) entered into the bubble, forming a specific shape allowing temporal monitoring of the plasma bubble evolution over time [72].

Under the concept of using robots to implement intelligent assembly work in space, also called iSpace, a space located distributed sensor network is deployed. In this system the robots simple follow a well-structured sequence procedure, they sense gathering information about humans and other objects in the space and actuate appropriate functions based on “observe”, “recognize”, and “actuate” [73].

Further considerations for UWS nodes working under SEE with large coverage area are dynamic in nature and usually face resource constraints. An efficient communication protocol with self-calibration will allow transport of real sensed phenomena from node to destination quickly, accurately and reliably. The properties of self-calibration of the nodes and the whole network will enhance the performance in terms of improvement of accuracy as well as reliability of the system. A temperature-assisted clock synchronization self-calibrated scheme with dynamically compensated clock skew for a sensor network has been proposed in [101]. The scheme relies only on local information without any requirement of exchange of time stamp leading to reduction in communication overhead in clock synchronization. A real-time and reliable transport (RT)² protocol has been presented [102] to transport event features reliably and collaboratively from sensor node to coordinator with minimum energy dissipation. For this provision of a reliable data dissemination service, sprinkler for wireless embedded nodes constrained in energy, processing speed and memory has been reported [103]. Design, implementation, and evaluation of a secure, lightweight, and Denial-of-Service-resistant data discovery and dissemination protocol named SeDrip for conventional WSN has been proposed [104]. An information dissemination model with explicit stopping criteria for wireless mobile sensors under harsh environments has been proposed to enhance the reliability of the network [105].

VII. CONCLUSION

Following a systematic examination of important issues associated with the adoption of conventional WSN for wireless sensing applications of SEE in networking architecture, synchronization, cooperative network management, dynamic spectrum sharing, and energy efficient multiple access techniques, we have discovered a number of critical incompatibilities between conventional WSN and most needed agile and dynamic style WSS-SEE applications. The proposed UWS approach for deployment of new applications, these environments are shown to be the best way to handle future developments. Upon analyzing the six groups of WSS-SEE applications we propose building a new WSS-SEE application platform using the UWS approach to enable our industries to handle a great opportunity waiting behind the development of such small but complex heterogeneous processes that would serve us all and lead to a new application paradigm.

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