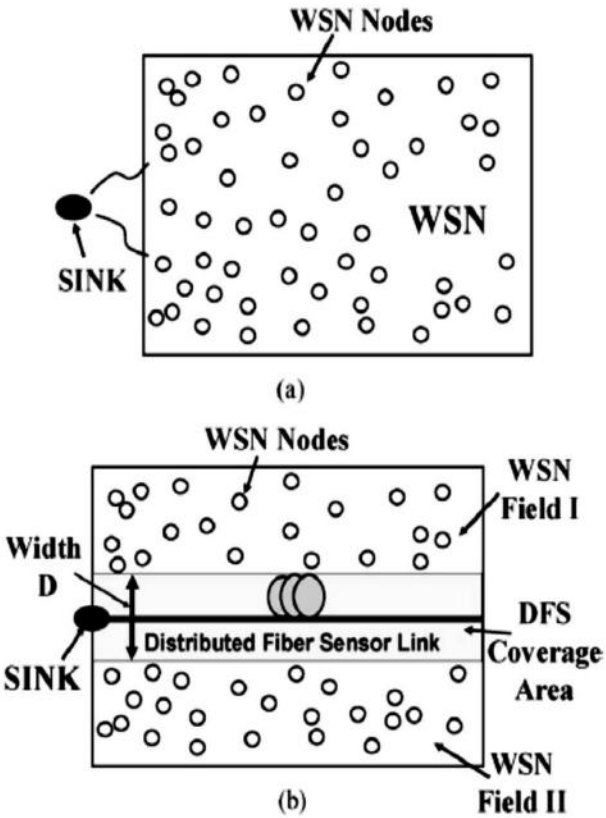

Figure. 1. (*a*) Illustration of aWSN with randomly scattered nodes (sink node: no Energy restriction; WSN nodes: with energy restriction); (*b*) Sensor field consistingof a DFS link and two WSN fields (I and II), the sink node is located at one end of the DFS and the width of the DFS coverage area is D.

II. O-LEACH PROTOCOL

As only nodes of two WSNs are energy or power limited, the protocol is mainly dealing with these nodes, starting from random node positioning outside the DFS coverage area, while inside the phenomenon. As the LEACH protocol is one of most popular WSN protocols, here we only give a brief introduction about that and more details could be found in [1] and [5]. LEACH is a cluster-based protocol. In the protocol, the sensor nodes in the network are divided into a number of clusters, the nodes organize themselves into preferred local clusters, a sensor node is selected randomly as the cluster head (CH) in each cluster and this role is rotated to evenly distribute the energy load among nodes of the network. The CH nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the BS in order to further reduce the amount of information that must be transmitted to the BS, thus reducing energy dissipation and enhancing system lifetime. After a given interval of time, randomized rotation of the role of CH is conducted to maximize the uniformity of energy dissipation of the network. Sensors elect themselves to be local cluster heads at any time with a certain probability. Generally only % of nodes needs to act as CHs based on simulation results. LEACH uses a TDMA/CDMA MAC to reduce inter-cluster and intra-cluster collisions. As data collection is centralized and performed periodically, this protocol is most appropriate when there is a need for constant monitoring by the sensor network.

The flowchart of the O-LEACH protocol is shown in Fig. 2. As the operation of the standard LEACH protocol is separated into the setup phase and the steady phase, we also separate the O-LEACH operation into two phases, and the steady phase is as same as the LEACH one [5]. During the setup phase, the selection of the cluster-head follows the similar criteria as LEACH, but there are two major differences between O-LEACH and LEACH: (*i*) nodes of WSNs cannot be deployed in the DFS coverage area (first check) and (*ii*) the cluster-head and the node should be within the same WSN field if two WSNs cannot communicate with each other (*i.e.*, checking in the flowchart).

For most applications, it would be better to assume that two WSN fields are isolated due to the following reasons: (i) saving information transfer energy since longer data transfer distance over the DFS terrain ends with higher energy consumption and (ii) wireless communication over the DFS area is not even allowed for some applications. However, we simulate the case that nodes inside different WSN fields can communicate with each other as well for reference. From the flow chart of the O-LEACH protocol, we have to admit the fact that the proposed protocol is only a fairly incremental modification to the original LEACH. The main point is to initiate the study about hybrid sensor networks with intriguing results.

III. SIMULATION RESULTS

Based on the O-LEACH protocol, we simulate the network performance in terms of the node lifetime. In our simulation model: 1) most of parameters (*e.g.*, probability of a node to become cluster head, data packet length, control packet length, etc.) are as same as other LEACH-based simulation models (listed in Table I) [5]–[7]; 2) the position of the sink in the LEACH model can be put in different places, while in our LEACH and O-LEACH ones, we put the sink of all the cases to the same position, i.e., in the middle of one edge of the sensor field (*i.e.*, the centre of one end of the DFS), although later in for the rectangular topology, we add a series of sinks to covermuch longer distances with more evenly distributed energyconsumption; 3) as the network energy dissipation is a totallystatistical behaviour due to the random distribution of WSNnodes, we simulate every case for 1000 independent iterations (it takes days to get such statistical results); and 4) as the ONS (DFS) is totally active

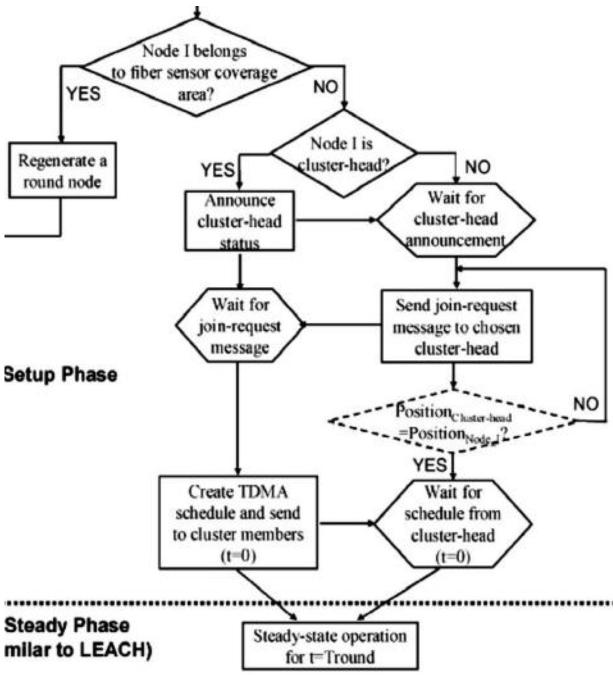

Figure 2. Flowchart of the O-LEACH protocol.

Dimension of sensor field (a.u.)	100x100
Probability to be cluster head	0.05
Data packet length	4000
Control packet length	200
Initial energy (J)	0.5
Energy dissipation of one Tx (J)	5e-8
Energy dissipation of one Rx (J)	5e-8
Energy loss - free space (J)	1e-11
Energy loss - multipass fading (J)	1.3e-15
Data aggregation energy (J)	5e-9

(*i.e.*, no energy constraint), the lifetime of the DFS is not considered. First, we compare the network performance in terms of the lifetime. Three cases are simulated: original LEACH without DFS; O-LEACH with varying the width of DFS coverage area (D) that two WSNs either can or cannot communicate with each other. As people use different parameters to evaluate the lifetime, *i.e.*, the round number corresponding to the appearance of the first dead node, half of dead nodes or the last survival node (called as "first-dead," "half-dead," and "fully-dead" in the following part of the paper), we obtain all three parameters and find that network improvement may end with quite different results through these parameters. A node is considered to be dead if the remaining energy is zero [5], although reduced communication reliability may happen during the energy depletion. Note that in most practical applications, the DFS coverage is very specific and cannot be freely varied. While sometimes parallel DFS links may be deployed to cover more broad areas, therefore, the DFS coverage width is varied in our simulation for the purpose of comparison and possible reference.

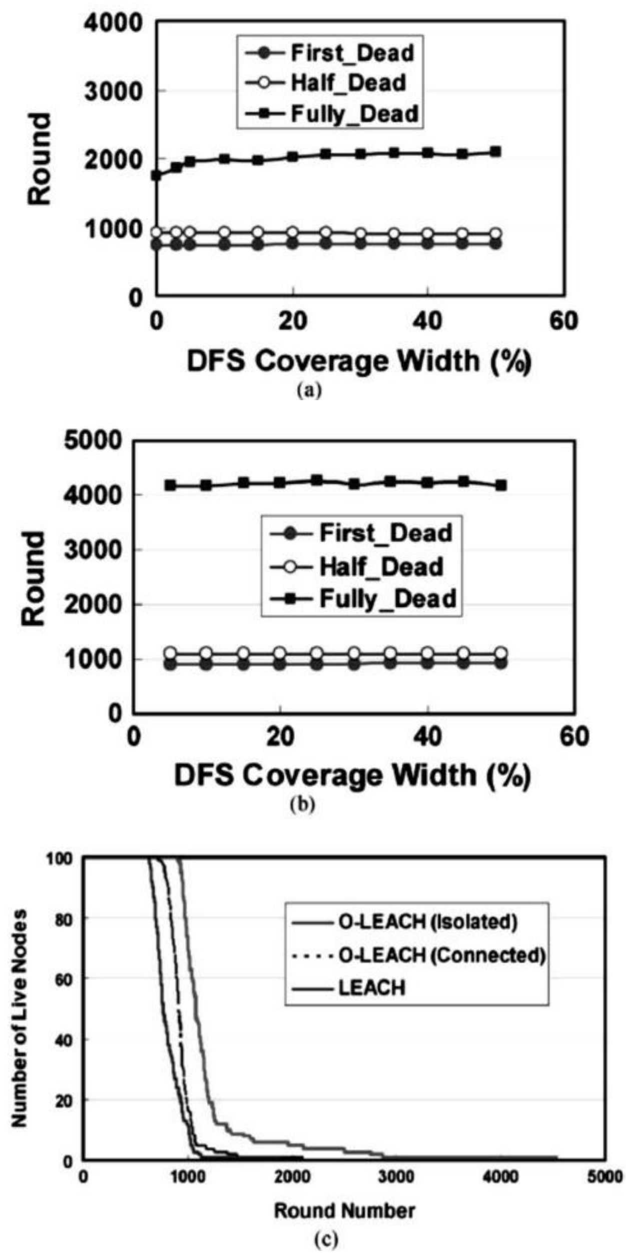

Figure 3. Simulation results of network performance in terms of lifetime (round number) using O-LEACH protocol. (*a*) Two WSNs can communicate with each other. (*b*) Two WSNs are isolated. (*c*) Typical lifetime evolution curves.

For the LEACH case, we obtain the average round number corresponding to "first-dead," "half-dead," and "fully-dead" are 731, 915, and 1741, respectively. Figure 3(*a*) and (*b*) show the average lifetime evaluated by three "-dead" parameters for situations that the two WSNs can and cannot communicate with each other as we vary the value of D (from 5 to 50).We can see that: 1) The network performance in terms of lifetime keeps almost constant regardless the width of DFS coverage. 2) In the case that two WSNs cannot communicate with each other, nodes can save energy on broadcasting over smaller area (*i.e*., shorter distance), therefore, the average lifetime corresponding to either “first-dead” or “half-dead” is improved % compared to the case that two WSNs are connected (the average round number from 731 to 903 and from 915 to 1086 for “first-dead” and “half-dead”, respectively), while the last node’s lifetime (“fully-dead”) is more than doubled. 3) Compared to the conventional LEACH protocol, the improvement of O-LEACH if two WSNs can communicate with each other is very limited (% and % in terms of “first-dead” and “fully-dead,” respectively. In fact, such improvement is simply converged to the original LEACH case if we further reduce the coverage percentage, *i.e.,* %). Therefore, it is expected and mostly required for such hybrid sensor networks to employ O-LEACH with two WSNs isolated. Furthermore, typical lifetime evolutions are compared as well in Figure 3(c), where D equals 20.These curves are specially chosen from thousands of simulated iterations with performance close to average ones. Results of LEACH protocol are also included. A legitimate question for above network model is how close the reality of the hybrid sensor network in terms of the coverage of DFS and WSN. As mentioned in the introduction section,the distance of typical DFS link can vary from hundredsof meters to tens of kilometers, while the coverage diameter ofWSN node is tens of meters. Therefore, it would be interestingto look into the case that the length of DFS link increases andthe number of WSN nodes increases proportionally (to keep theapproximate density).

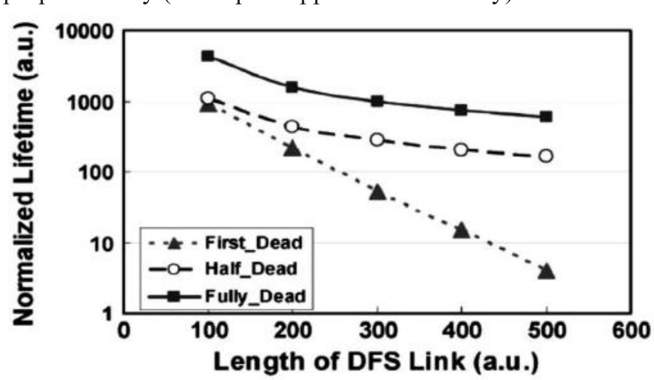

Figure 4. Normalized lifetime as we increase the length of DFS link (number of WSN nodes are increased proportionally, the widths of the DFS coverage area and the whole sensor field are fixed).

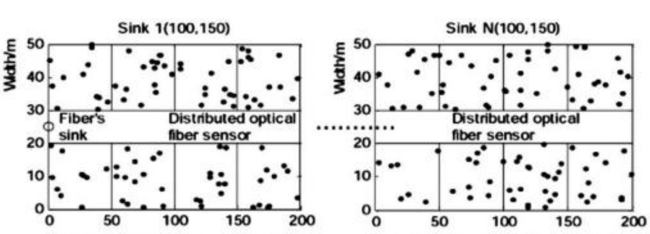

Figure 5. The topology incorporating distributed optical fiber sensors.

To keep straightforward but simple, we fix the width of the whole sensor field to 100 and the coverage percentage of DFSto 20% (*i.e.*, D equals to 20). Also, we only consider the case thattwo WSNs are isolated. Fig. 4 illustrates the trend of normalized lifetime performance with increasing link length of DFS. The normalization is done using the ratio of the “-dead” parameterto the total node number. It is obvious that 100 is the optimum number for WSN nodes with parameters listed in Table I. As thelength of the DFS link increases, the lifetime reduces dramatically, especially the “first-dead” parameter.

More wireless sinksare required for longer DFS links, and the performance evaluationof various optical wireless sensor network topologies areof great interests. More practically, the number of base stations (sinks) should be increased (or linked into series) to sustain thelong rectangular sensor field. Therefore, as a more general topology, Figure 5 shows such hybrid sensor networks that have potential to cover much more broad areas under certain guidelines: 1) cascade of multiple rectangular regions in which the base station location of WSN sensor node is (100, 150) and 2) the DFS is located in the monitor area with massive volume of data, harsh environment, and poor security (located in the middle of the rectangular region for this paper) to link the rectangular region and the location of fiber’s base station is (0, 25).

The DFS can cover a certain area as previously discussed, for example 10 m (vertical axis), to monitor the required (*e.g.,* temperature, strain, etc.) information within the coverage area, and give the data back to the fiberbase station (still located at the center of one end of the DFS andwith no need to worry about its power consumption).

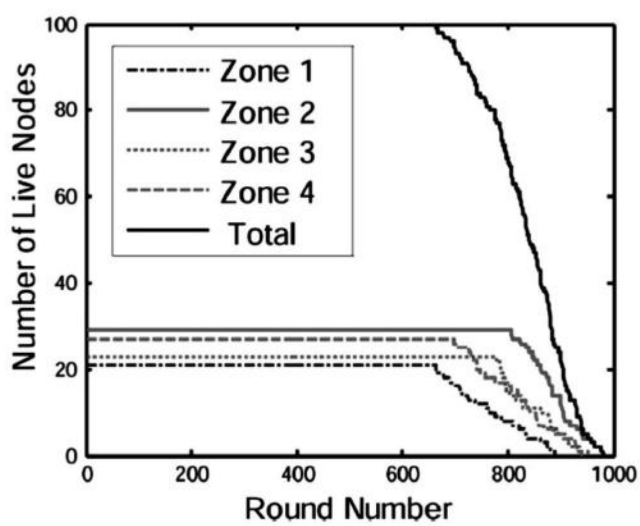

Figure 6. Performance (number of live nodes versus round) after introducing the DFS into the rectangular sensor area.

For more general topology of the hybrid OSN (DFS) andWSN network, we modify the O-LEACH algorithm and simulate a rectangular sensor network region that is divided into four small regions *(i.e.,* in Figure 5). In the total area, we randomly scatter 100 nodes, *e.g*., the number of nodesin each region is 21, 29, 23, and 27, respectively. The DFS is located in the middle of the total rectangular region as usual. We assume that the nodes in the upper and the lower part of theoptical region can communicate with each other, and the simulation results are shown in Figure 6. We can see from Figure 6 that the round numbers of the first dead node in the four regions are 663, 805, 779, and 698, respectively.The first 20% of nodes die slowly, but the remainingones die rapidly in the total region. The results further demonstratethat the hybrid sensor network incorporating DFS with the O-LEACH protocol can evenly distribute the energy load amongnodes, therefore prolong the overall lifetime of the network.

IV. CONCLUSION

We investigated a modified energy-efficient communication protocol, called O-LEACH, for wireless sensor networks that consist of DFS links and randomly scattered wireless sensor nodes. Survival round numbers of WSN nodes are simulated for various cases using different parameters. The lifetime of the situation that two WSNs are isolated is more than 20% better than that of the case where nodes inside two WSN fields are reachable to any live nodes within the whole sensor field. This can be a deployment guideline for such hybrid sensor networks.

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EBG Structures and Their Implementation in Microstrip Antenna Designs

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Abstract: **In the context of modern Antenna and Microwave filter design, Electromagnetic Bandgap Structures (EBGs) are considered as the ideal basic building blocks. Electromagnetic band-gap structures are defined as artificial, periodic, high-surface impedance structures that reject or allow the propagation of electromagnetic waves in a specified frequency band. In the EBG bandgap, the surface impedance of EBG structures is high; this makes them most suitable to be used under an antenna that needs to be placed close to a ground plane. EBG structures have the inherent capability to suppress undesired surface waves in various antenna engineering applications.**

For RF and microwave researchers, the EBG terminology is a challenging research sector to offer solutions to many problems that degrade the functional efficiency of a system.

The current paper presents a comprehensive review of various types of EBG structures, their topologies and design parameters. Additionally, it describes the procedures undertaken in modern antenna design. Finally, it has been established that an optimized, well designed EBG structure could result in tremendous improvisation in the performance of a Microstrip antenna and other microwave devices. Furthermore, selection of a proper dielectric structure may prove to be a vital factor in overall antenna design.

Keywords: Electromagnetic Band Gap Structures, Insertion Loss, S-Parameters, Artificial Magnetic Conductors.

I. INTRODUCTION

ELECTROMAGNETIC band gap structures are artificially fabricated periodic structures designed with reactive components. They suppress or assist the propagation of electromagnetic waves in a specified band (bandgap) of frequencies for all incident angles and all polarization states. EBG structures are equivalent to magnetic surfaces at resonant frequency and exhibit very high impedance. These structures are usually realized by etching periodic mushroom like square patches on a dielectric board connecting the patches to the ground plane. EBG structures are widely used in antenna engineering applications as they are compact, lightweight, easy to manufacture, and have low loss over a small band. The present research lays emphasis on the shielding property of the EBG to reduce specific absorption rate or SAR (back radiation) into mobile phone operator's hand and head.

A microstrip patch antenna is a printed type of antenna consisting of a substrate sandwiched between a ground plane and a patch. Patch antennas exhibit characteristics such as light weight and a low profile which makes these antennas desirable for many applications.

The surface waves are bye products in these antenna designs. These waves are directed electromagnetic waves propagating along the ground plane instead of radiation into free space, thus reducing the antenna efficiency and gain. Microstrip patch antennas offer an attractive solution to compact, low-cost designing of modern wireless communication systems. Furthermore utilization of planar configuration in the design makes it suitable with respect to the host surface. This reduces the overall cost and makes it compatible for dual and triple frequency operations in comparison to their three dimensional counterparts.

In the current scenario, due to availability of advanced computing machines and computational electromagnetic tools, design and development of new antenna technologies has become possible. These tools have made analysis, synthesis and optimization of new generation antennas easier and faster. The tools include various time domain solvers (*e.g.* finite-difference-time-domain or FDTD) and frequency domain solvers (*e.g.* method of moments or MoM and finite element method or FEM). Due to the available computing machines and full wave solvers, complex antenna packaging with feed networks and surrounding materials can be analyzed effectively. The final design can be simulated before actual hardware implementation and the entire packaging can be optimized to achieve the best possible performance. Thus the entire antenna designing procedure has transformed from an orthodox mode to a highly sophisticated mode.