ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 4, April 2016

REVIEW ON UNDER WATER ACOUSTIC SENSOR NETWORK

Agnihotri Sinha[1], Inderjeet Yadav [2]

M-Tech Student[1,] Assit. Prof. [2] & Department of CSE & NGF College of Engineering &Technology
Palwal, Haryana, India

Abstract
This paper explains briefly our research directions in the field underwater sensor networks. We explain potential applications to off-shore oil fields for equipment monitoring, seismic monitoring and underwater robotics. We describe research directions in MAC, short-range acoustic communications, localization protocols and time synchronization for high latency acoustic networks, application level time scheduling and long-duration network sleeping.

Keywords: USN, MAC, WSN

I. INTRODUCTION

Sensor networks have the promise of developing several fields of industry, science and government with their capability to bring sensing and computation into the physical world. The capability to have small devices physically disseminated near the objects being observed brings new chances to notice and perform on the world, for instance with structural monitoring [6], micro-habitat monitoring [9, 11] and broad-area environmental systems [7]. Industrial applications i.e. production lines and oil fields employ wide instrumentation, today frequently as cautiously engineered SCADA systems, but increasingly with more frequently distributed sensor networks [9]. Advances in decreasing sensor size and cost imply that they can be cheap and small enough to be spread. The fact that these devices can intercommunicate means that they can collaborate and relay data to remote subscribers, operating unattended. Advancement in energy efficiency mean that devices can notice subjects long-term trends. While sensor-net systems are starting to be fielded in applications currently on the ground, underwater operations remain quite restricted by comparison. Remotely managed submersibles are generally utilized, but as active, large and maintained devices, their deployment is inherently local. Many wide-area data gather attempts have been contracted, but at quite common granularities (hundreds of sensors to deal with globe) [8]. Even when regional methods are taken, they are generally wired [16]. The key advantages of terrestrial sensor networks root from self-configuration, wireless operation and increasing the utilization of any energy taken. We are now explaining how to increase these advantages to underwater sensor networks with acoustic communications. It is Terrestrial networks stresses on less cost nodes (about US$100), dense deployments (maximum a few 100m apart), short range communication, multi hop communication by comparison, typical underwater wireless communication currently are generally costly (US$10k or more), sparsely distributed (a few nodes, positioned kilometers apart), generally communicating directly to a BS. We try to reverse every design points, developing underwater sensor nodes that can be cheap, densely distributed, and communicating peer-to-peer.

Underwater sensor networks have several potential applications, involving equipment monitoring, seismic monitoring and leak detection, and provide support for swarms underwater robots. Here we shortly consider seismic imaging of undersea oil fields like a representative application. One major cause to select this application is that underwater sensor network is capable to offer important economic advantages over conventional technology. Today, most seismic imaging tasks for offshore oil fields are enforced by a ship that bundles a large array of hydrophones on the surface [10]. This technology is very expensive, and the seismic survey can only be enforced seldom, for instance, once every 2.3 years. In comparison, sensor network nodes are not very expensive, and can be permanently distributed on the sea floor.

II. SECURITY DEMANDS OF UAN

A. General Security Goals of Networks

Proper information transfer among nodes is the primary objective of a network. To fulfill this goal, there are various general objectives of a network related to security [11].

- **Availability:** This implies that the network resources are allocated to established parties and should confirm the availability of network services in any situation.
- **Data Confidentiality:** The network should ensure That information which is transferring between nodes does not leak to other nodes.
- **Data Authentication:** To permit the recipient to assure that the data were really sent by the authorized sender.
- **Data Freshness:** This means that the datasets are latest, and it confirms that no antagonist reproduces old messages.
- **Data Integrity:** To confirm the recipient that the Obtained data are not modified during transfer by an antagonist

B. Challenges of Secure UAN

Features and application of UAN Directly bring some security issues [12], [13]:

- **Challenge 1:** The UAN nodes have high processing and storage abilities in comparison of ASN and WSN, still, the power supply of UAN is consumable and limited. Excluded the basic functions, extra operation would cause into a conflicting interest between reducing resource utilization of UAN nodes and enhancing security performance.
- **Challenge 2:** The underwater acoustic communication features related to UAN provide conventional wired-based security strategies. Serious ISI (inter symbol interferences), large time delay etc. bound complicated measures to be taken into account.
- **Challenge 3:** Threats to UAN can come from any directions and target at any nodes because of the networking configuration. Sparse configuration and large scale build the network easy to be attacked but complicated to protect.

C. Demands on Security of UAN

Previous mentioned basic objectives of networks are also essential to UAN. Regarding to the strong formation of UAN, the UAN security lies in three levels [14]:

- **Node security:** If a node, the physical basis of UAN i.e. the cluster heads or gateway is damaged, the network would not operate any more.
- **Communication security:** UAN "nerves" is communication. If it cannot be confirmed, the network will decrease to an assembly of many individual devices.
- **Protocol security:** The control system of UAN, protocol without this, the operations would work into confusions. The previous two kinds of security considerations are the general poles of secure network, while the latter one –

Protocol security is much more complicated, which is primarily enquired in the further sections. *C.*

III. SYSTEM ARCHITECTURE

Before explaining particular applications, we next shortly review the general architecture we see for an underwater sensor network. We start by taking the rough abilities of each underwater sensor node, how it communicates with its environment, application and other underwater nodes. Figure 1 illustrates a logical diagram of a potential system. We view four different kinds of nodes in the system. At the lowermost layer, the large no. of sensor nodes to be positioned on or close to the sea floor (illustrated in small yellow circles in the figure). They have moderate computing power, price and storage capacity. They gather data by their sensors and communicate with other nodes by using short-range acoustic modems. They have batteries, but for long-term operation they expend most of their life at rest.

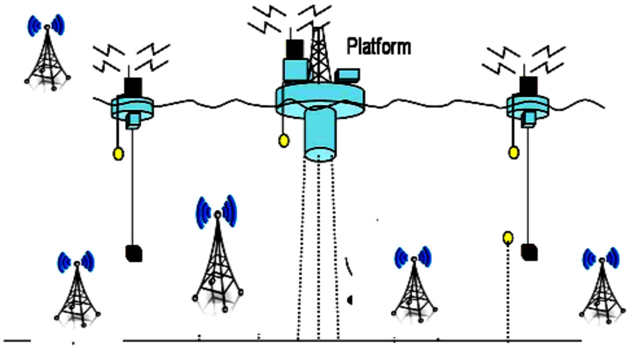

Figure 1. One possible approach to node deployment

At the uppermost layer, there are one or more control nodes with links to the Internet and perhaps human operators. These control nodes may be located on an off-shore platform with power, or they may be on-shore; we want these nodes to have a wide storage capability to store data, and access to enough electrical power. Control nodes will intercommunicate with sensor nodes directly, through a relay node: a sensor node with underwater acoustic modems that is linked to the control node with a wired network.

In wide networks, a third kind of nodes, known as *super nodes*, have access to higher speed networks. We are taking two possible implementations: first includes connecting regular nodes to attached buoys that are fitted with high-speed radio communications to the BS, as explained in the fig. An alternative implementation would position these nodes on the sea surface and link them to the BS with fiber optic cables. Irrespective of the specific implementation, the significant feature of super nodes is that they can pass data to the BS very effectively. These super nodes permit much richer network connectivity, making several data collection points for the underwater acoustic network.

At last, though robotic submersibles are not the stress of the current work, we view them interacting with our system through acoustic communications. In the figure, dark blue ovals show multiple robots facilitating the platform.

IV. APPLICATIONS

We view our methods as suitable to a no. of applications, involving equipment monitoring, seismic monitoring and leak detection, and provide support for swarm underwater robots. We examine the various features of each of these below.

Seismic Monitoring: A predicting application for underwater sensor networks is seismic monitoring for oil extraction from underwater fields. Rapid seismic monitoring is of significance in oil extraction; studies of version in the reservoir over time are known as 4-D seismic and are important for estimating field performance and motivating intervention.

Equipment Monitoring and Control: Underwater equipment monitoring and control is a second example of application. Most preferably, underwater equipment will involve monitoring support when it is positioned, possibly linked with attached power and communication; Hence our methods are not essential. Since, *temporary* monitoring would advantage from low-power wireless communication. Temporary monitoring is most useful when equipment is first positioned, to assure successful deployment during starting operation, or when problems are discovered. We are not taking node deployment and fetching at this time, but predictabilities involve remote-vehicles or robotic operated or divers.

Flocks of Underwater Robots: A third and different application is provide support to groups of underwater self-directed robots. Applications involve cooperating adaptive sensing of chemical leaks or biological process (for instance, oil leaks or phytoplankton concentrations), and also equipment monitoring applications as explained above.

V. HARDWARE FOR UNDERWATER ACOUSTIC COMMUNICATIONS

We have explained why underwater *acoustic communications* is a significant option to radio-frequency (RF) communications for these type of networks. At the hardware level, underwater acoustic communications is same as RF communications in air, but with some differences. In both systems we transmit a carrier or tone. This carrier is regulated by the data that we are forwarding. Common modulation techniques involve changing the carrier frequency (FM), the carrier amplitude (AM), and the carrier phase (PM). Modulation can happen in a stepped (digital) or continuous (analog) fashion. The main differences between these modulation methods remains in the complexity of the recipient, the bandwidth needed, and the minimum acceptable obtained signal-to-noise ratio.

Transmit Power:

There is no key restriction to transmitter power, but it can have a wider impact on the system power budget. For energy efficiency and to reduce interference with nearest transmitters we want to utilize the minimum possible transmitter power.

Data Rate:

This is a tradeoff in the system design, depending on channel bandwidth and existed power. Because acoustic communications are possible only over fairly restricted bandwidths, we wish a suitable low data rate by comparison with most radios. We view a rate of currently 5kb/s and perhaps up to 20kb/s. luckily, these rates are within an order of RF-based sensor networks magnitude.

Signal Attenuation:

Signal attenuation is because of a variety of factors. Both acoustic waves and radio waves observe $1=R2$ attenuation because of spherical spreading. There is also absorptive loss because of by the transmission media. For RF transmission, atmospheric losses are rather less. Absorptive losses in underwater acoustics are important, and very dependent on frequency. At 12.5 kHz absorption it is 1 dB/km or small. At 70 kHz it cans more than 20 dB/km. This positions a practical upper limit on our carrier frequency at approx. 100kHz. Some of these kinds of loss are unique to acoustic communications at *larger* distances. Specifically, temperature variation, multipath reflections and surface scattering are all amplified by distance. Inspired by the advantages of short range RF communication in sensor networks, we try to feat *short-range underwater acoustics* where our only important losses are absorption and spreading. We are formulating a multi-hop acoustic network directing communication distances of 50-500 meters and communication rates of about 5kb/s.

VI. PROTOCOLS FOR HIGH-LATENCY NETWORKS

Acoustic communication places new restraints *networks* of underwater sensor nodes for various reasons. First, high propagation delay may break or importantly reduce some current protocols performance. The sound speed in sea water is approx. 1:5_103m/s. The delay in propagation for two nodes at 100m distance is approx. 67ms. Second, the acoustic channel bandwidth is much lesser as compared to a radio. Effective bandwidth usage becomes a significant issue. These restraints force us to review available networking protocols and, in some situations, substitute them with enhanced protocols designed explicitly for this high-latency environment. At last, terrestrial networks can take benefit of rich available infrastructure i.e. satellite communications networks and GPS. This restraint forces underwater sensor networks to be self-directing in ways that terrestrial networks may not be. We next analyze various research directions to offer this support for the USN.

i. Latency-Tolerant MAC Protocols

MAC protocols proper for sensor networks can be widely categorized into two classes: contention-based protocols and scheduled protocols [61]. TDMA is a typical instance of the scheduled protocols. It has better energy efficiency, but it needs strict time synchronization and is not elastic to changes in the no. of nodes. Contention based protocols are generally depend on CSMA, and many collision avoidance methods, i.e. RTS/CTS exchange, are also normally utilized. Contention-based protocols have well adaptively and scalability to changes in the no. of nodes.

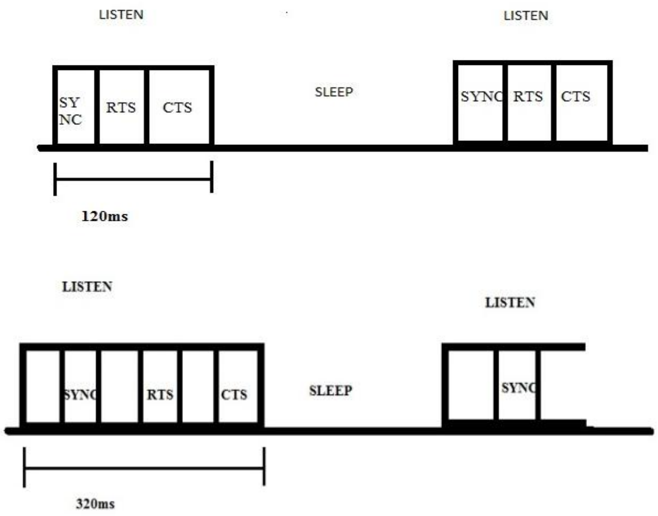

Figure 2. Modified S-MAC schedules to accommodate large propagation delay. (a) Shows the listen window length currently implemented in Tiny OS. (b) Shows increased listen window to accommodate propagation delay of each packet.

Figure 2. Illustrates the periodic listen and sleep schedule of a sensor node operating S-MAC in low duty cycles The top part (a) illustrates the listen window length in current implementation in TinyOS, which is approx. 120ms for listening RTS, SYNC and CTS packets. The bottom part (b) explains a primitive extension to S-MAC where we change the listening window to adapt the propagation delays for every packet, now approx. 320ms. With this primitive mechanism, a propagation delay will importantly increase the actual duty cycles of nodes, decrease throughput, increase latency and particularly in multi-hop networks.

ii. Time Synchronization: Time synchronization offers key support for several protocols and applications. Without GPS, time synchronization algorithms have to be totally distributed over peering nodes. Various algorithms have been formulated for radio-based sensor networks, obtaining the accuracy of tens of microseconds [19, 22]. Since, they consider nearly instantaneous wireless communication among sensor nodes, which is valid enough (0.33μs for nodes more than 100m) for current RF-based networks.

The primary concept in TSHL is that it separates time synchronization into two phases. In the first phase, nodes describe their clock skew to a centralized time base, after which they become *skew synchronized*. In the second phase they exchange *skew compensated* synchronization messages to find their accurate offset. The first phase is imperviable to the propagation latency, while the second phase explicitly deals with propagation delay produced errors. This results in fast relative synchronization (end of phase 1), and also permits us to perform *post-facto* synchronization. Both properties are highly required in our desired application.

iii. Localization: Localization is the phenomenon for every sensor node to position its locations in the network. Localization algorithms formulated for terrestrial sensor networks can be widely categorized into two categories. The first class depends on signal strength evaluation [3, 5]. These algorithms are significant to provide nodes proximity information with less cost, but they are not capable to offer exact location information. The second class is capable to offer fine-grained position information, which is needed by our seismic imaging applications. These algorithms depend on evaluating the signal propagation time, *such as* the time-of-arrival (TOA) [12, 23]. Their general principle for range measurement is similar to sonar or radar, but it is performed in a distributed manner between peering nodes. TOA measurement needs precise time synchronization between a receiver and a sender.

iv. Network Re-Configuration after Long Duration Sleeping: Undersea seismic monitoring of oil fields is a “nothing or all” application-periodically a seismic experiment will be activated and all nodes must gather high-resolution seismic data for a very less time, then a few months may pass by with no activity. It would be really wasteful to hold the network fully enable for months at a time to provide support to occasional evaluations. Rather than, we wish to put the complete network to sleep for the whole inactive period, decreasing the duty cycle to a small percentage of deployment time. Similar methods are also suitable for long-term equipment monitoring, where nodes only require to examine equipment status once in a day or in a week [39].

v. Application-Level Data Scheduling: Besides energy restraints, acoustic networks also have very restricted communications bandwidth. Current off-the shelf acoustic modems generally have the bandwidth around 5.20Kb/s. With applications i.e. seismic imaging, all nodes will gather and attempt to forward large amount of data that can easily overcome the capacity of network. The research work here is how to collaborate node's transmissions in an energy effective way that can best use the channel.

VII. UW-ASNs ARCHITECTURE

In this section, we explain the communication framework of underwater acoustic sensor networks (**UW-ASNs**). The mention architectures explained in this section are utilized as a basis for discussion of the issues related with underwater acoustic Sensor networks. The underwater sensor network configuration is an open research challenge in itself that requires further analytical and simulative analysis from the research group. In remaining section, we talk about the following architectures:

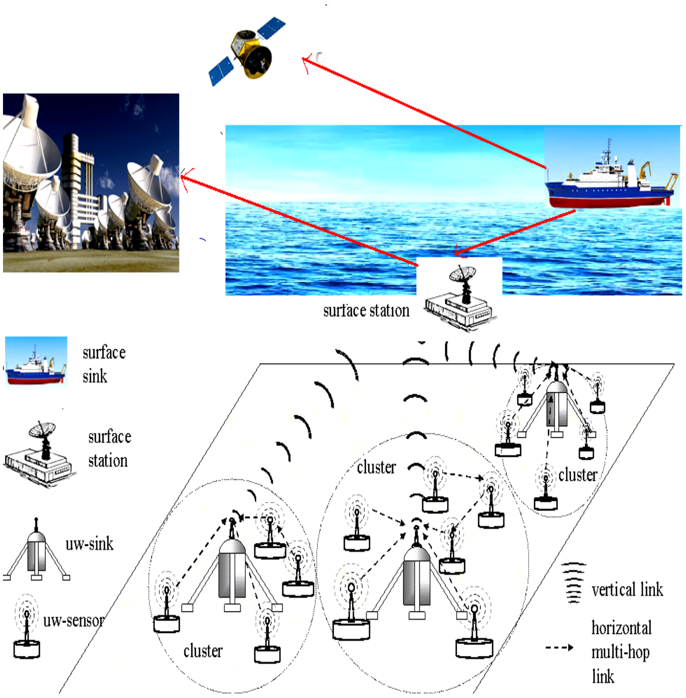

Fig. 2.1 Architecture for 2D Underwater Sensor Networks

Static two-dimensional UW-ASNs for ocean bottom monitoring.

These are formed by sensor nodes that are fixed at the bottom of the ocean. Some significant applications may be supervision of underwater plates in tectonics [4] and environmental monitoring,

Static three-dimensional UW-ASNs for ocean column monitoring

These include sensors networks whose depth can be managed by use of some methods explained in Section II-B, and may be employed for supervision of ocean phenomena (water streams, ocean biogeochemical processes, pollution, etc) and surveillance applications.

Two-dimensional Underwater Sensor Networks

Mentioned architecture for two-dimensional underwater networks is explained in Fig. 2.1. A sensor node group is fixed at the bottom of ocean with deep ocean anchors. By usage of wireless acoustic connections, underwater sensor nodes are linked to one or more underwater sinks (uw-sinks), which are network assets in charge of controlling data from the bottom of ocean network to a surface station. To get this goal, uw-sinks are fitted with two acoustic transceivers, namely a horizontal and vertical transceiver. The horizontal transceiver is utilized by the uw-sink to communicate with the sensor nodes in for i) sending commands and configuring data to the sensors (uw-sink to sensors); ii) gather supervised data (sensors to uw-sink). The vertical link is utilized by the uw links to control data to a surface station. Vertical transceivers are used for deep water applications because the ocean can be as deep as 10 km, they must be long range transceivers. The surface station is fitted with an acoustic transceiver that is capable to deal with more than one parallel communications with the deployed UW-sinks. It is also equipped with a long range satellite or RF.

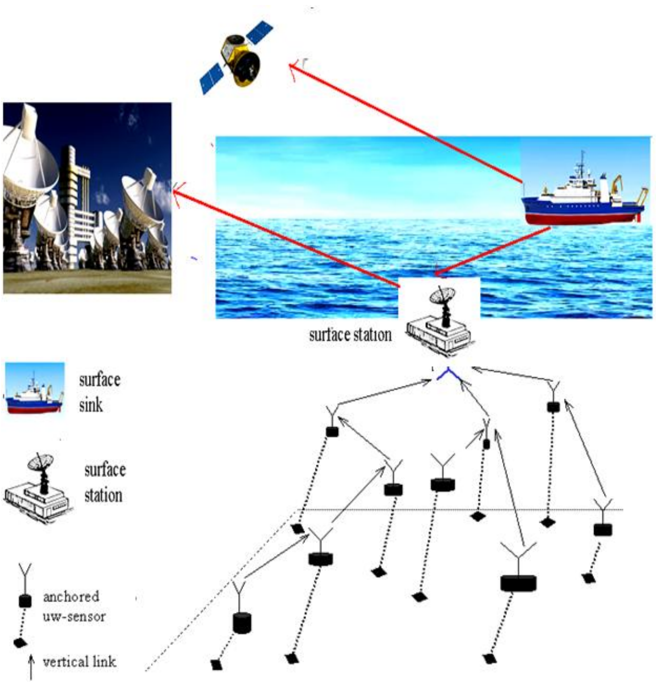

Fig. 2.2 Architecture for 3D Underwater Sensor Networks

VIII. DESIGN CRITERIA

The establishment of practical underwater networks is a complicated task that needs a large range of abilities. Not only physical layer must supply reliable connections in all environmental circumstances, but there are number of protocols that are needed to provide support to the network maintenance ad discovery as well as message formation, interoperability, and system security.

As electromagnetic waves do not travel properly underwater, acoustics plays a significant role in underwater communication. Because of important differences in the features of acoustic and electromagnetic channels, the configuration of viable underwater networks requires to take into consideration a wide variety of various constraints. The frequency-dependence, long delays, and extreme limitations in obtainable bandwidth and link range of acoustics should be of main issue at an early design phase in addition to throughput, power efficiency, and system reliability. These components build underwater networking a main and honoring enterprise. In this chapter, some important views to be taken into account when establishing an underwater communication system are examined for example, the explanation of the framework where the network is said to be positioned, general assumptions and technical criteria.

Seismic imaging in oil industry: Three-dimensional (3-D) seismic imaging and monitoring is an important technology for oil exploration and reservoir management in the oil industry. Advanced reservoir management with 3-D seismic (sometimes 4-D with time series) can significantly improve resource recovery and oil productivity. We introduce a new mechanism for underwater seismic utilizing underwater WSN. The sensor network is composed of large no's of smart sensors, and every network has an embedded sensors, processor, sensors, acoustic communication devices and storage memory. These nodes are battery powered, and are deployed in an ad hoc way without careful planning. Once positioned, the nodes will configure themselves into a multi-hop communication network, and slowly move sensing data back to subscribers.

Oceanographic research: Another concerned community is the oceanography, where investigators have formulated underwater communication and sensing systems. An instance is the Ocean Seismic Network program [48]. It formulated seismic observatories in the deep ocean, as type of the Global Seismic Network (GSN). GSN has 128 observatories uniformly positioned on islands, continents or in the ocean, with a distance of 2000km. Its objective is to manage a large area on earth. In opposite, our sensor network deals with a much smaller region and nodes are densely demonstrated in an ad-hoc fashion. In GSN, there is no direct communications among the sensing stations. They all directly forward their data in return to a central place. In sensor networks, the nodes will set up themselves to make a multi-hop communication network. In brief, the GSN is however the conventional way to do seismic imaging, but it deals with a large area involving ocean nodes.

Wireless Sensor Networks: Utilizing WSN for seismic imaging is not a novel concept in the sensor network community. But all available work depends on radio communications between sensors. Our objective is to explore sensor networking techniques to underwater applications with acoustic communications. Further, almost all *platforms* formulated for WSN utilize radio communications. One of most broadly utilized platforms is the UC Berkeley mote [26, 14], which depend on a short-range, low power radio and 8-bit microcontroller. 32-bit platforms are generally embedded PCs, i.e. Stargazes and PC/104s [15]. These nodes do not have in-built radios, but can be linked with either IEEE 802.11 cards or motes. Though the propagation of radio in water is very bad, the motes are however utilized by investigators in marine microorganism monitoring applications [8, 64]. We wish to explore sensor network platforms with a short range, low-power acoustic communication device, in order to large-scale underwater applications and experiments become possible.

IX. LITERATURE REVIEW

These research works make on related work from various communities: the oil industry as a potential subscriber of underwater sensor networks, oceanographic researchers who make underwater communication and sensing systems, and the wireless sensor network community. While explaining available work, we will also describe what is new in our introduced research. [2]Here in this paper authors a detail review on under water acoustic sensor network had been carried out and several fundamental key aspect of underwater acoustic communication are investigated in their work author discusses various architecture of USN. In this paper author also offing main challenges of USN. [3] In this paper, authors perform detail review on under sensor network research challenges and its potential applications. In their work authors also identifying research direction in short range acoustic communication time synchronization and localization protocol for high latency acoustic network

CONCLUSIONS

This paper has explained briefly our ongoing research in USN, involving potential applications and research issues. Underwater sensor networks have several potential applications, involving equipment monitoring, seismic monitoring and leak detection, and provide support for swarms underwater robots. We describe research directions in MAC, short-range acoustic communications, localization protocols and time synchronization for high latency acoustic networks, application level time scheduling and long-duration network sleeping.

REFERENCES

[1] A. Abel and W. Schwarz, "Chaos communications-principles, schemes, and system analysis," Proc IEEE, vol. 90, pp. 691-710, 2002..

[2] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "A survey on sensor networks," Communications Magazine, IEEE, vol. 40, pp. 102-114, 2002.

[3] I. F. Akyildiz and M. C. Vuran, Wireless Sensor Networks. John Wiley & Sons, 2010.

[4] I. T. Almalkawi, M. G. Zapata, J. N. Al-Karaki and J. Morillo-Pozo, "Wireless Multimedia Sensor Networks: current trends and future directions," Sensors (Basel), vol. 10, pp. 6662-6717, 2010.

[5] D. Chen and P. K. Varshney, "QoS support in wireless sensor networks: A survey." in International Conference on Wireless Networks, 2004, pp. 1-7.

[6] J. dos Santos Coelho, Underwater Acoustic Networks: Evaluation of the Impact of Media Access Control on Latency, in a Delay Constrained Network, 2005.

[7] M. Erol-Kantarci, H. T. Mouftah and S. Oktug, "A survey of architectures and localization techniques for underwater acoustic sensor networks," Communications Surveys & Tutorials, IEEE, vol. 13, pp. 487-502, 2011.

[8] A. M. Fabregat, A. M. Fabregat and A. M. Fabregat, "Desenvolupament, proves de camp i anàlisi de resultats en una," 2008.

[9] N. Ismail, L. A. Hussein and S. H. Ariffin, "Analyzing the performance of acoustic channel in underwater wireless sensor network (UWSN)," in Mathematical/Analytical Modelling and Computer Simulation (AMS), 2010 Fourth Asia International Conference on, 2010, pp. 550-555.

[10] Jákó, Zoltán. "Performance Improvement of Differential Chaos Shift Keying Modulation Scheme." Thesis submitted to the Department of Measurement and Information Systems. Budapest University of Technology and Economics.

[11] M. C. Jeruchim, P. Balaban and K. S. Shanmugan, Simulation of Communication Systems: Modeling, Methodology and Techniques. Springer, 2000.

[12] P. Jurčík and A. Koubâa, "The IEEE 802.15. 4 OPNET simulation model: reference guide v2. 0," IPP-HURRAY Technical Report, HURRAY-TR-070509, 2007.

[13] G. Kaddoum, J. Olivain, G. Beaufort Samson, P. Giard and F. Gagnon, "Implementation of a differential chaos shift keying communication system in gnu radio," in Wireless Communication Systems (ISWCS), 2012 International Symposium on, 2012, pp. 934-938.

[14] M. P. Kennedy and G. Kolumbán, "Digital communications using chaos," Signal Process, vol. 80, pp. 1307-1320, 2000.

[15] M. P. Kennedy, G. Kolumbán, G. Kis and Z. Jákó, "Performance evaluation of FM-DCSK modulation in multipath environments," 2000.

[16] M. Kennedy, R. Rovatti and G. Setti, Chaotic Electronics in Telecommunications. CRC press, 2000.

[17] G. KOLUMBaN, K. GaBOR, J. Zoltan and M. P. Kennedy, "FM-DCSK: A robust modulation scheme for chaotic communications," IEICE Trans. Fund. Electron. Commun. Comput. Sci., vol. 81, pp. 1798-1802, 1998.

[18] G. Kolumban, M. P. Kennedy, Z. Jákó and G. Kis, "Chaotic communications with correlator receivers: theory and performance limits," 2002.

[19] G. Kolumban and T. Krébesz, "UWB radio: A real chance for application of chaotic communications," Proc.NOLTA'06, pp. 475-478, 2006.

[20] Kennedy, Michael Peter, and Géza Kolumbán. "Digital communications using chaos." Signal processing 80.7 (2000): 1307-1320.

[21] F. C. Lau and K. T. Chi, Chaos-Based Digital Communication Systems: Operating Principles, Analysis Methods, and Performance Evaluation. Springer, 2003.

[22] H. Leung, H. Yu and K. Murali, "Ergodic chaos-based communication schemes," Physical Review E, vol. 66, pp. 036203, 2002.

[23] H. Leung, S. Shanmugam, N. Xie and S. Wang, "An ergodic approach for chaotic signal estimation at low SNR with application to ultra-wide-band communication," Signal Processing, IEEE Transactions on, vol. 54, pp. 1091-1103, 2006.

[24] Y. Liu, I. Elhanany and H. Qi, "An energy-efficient QoS-aware media access control protocol for wireless sensor networks," in Mobile Adhoc and Sensor Systems Conference, 2005, IEEE International Conference on, 2005, pp. 3 pp.-191

[13] G. Kaddoum, J. Olivain, G. Beaufort Samson, P. Giard and F. Gagnon, "Implementation of a differential chaos shift keying communication system in gnu radio," in Wireless Communication Systems (ISWCS), 2012 International Symposium on, 2012, pp. 934-938.

[14] M. P. Kennedy and G. Kolumbán, "Digital communications using chaos," Signal Process, vol. 80, pp. 1307-1320, 2000.

[15] M. P. Kennedy, G. Kolumbán, G. Kis and Z. Jákó, "Performance evaluation of FM-DCSK modulation in multipath environments," 2000

[16] M. Kennedy, R. Rovatti and G. Setti, Chaotic Electronics in Telecommunications. CRC press, 2000.

[17] G. KOLUMBaN, K. GaBOR, J. Zoltan and M. P. Kennedy, "FM-DCSK: A robust modulation scheme for chaotic communications," IEICE Trans. Fund. Electron. Commun. Comput. Sci., vol. 81, pp. 1798-1802, 1998

[18] G. Kolumban, M. P. Kennedy, Z. Jákó and G. Kis, "Chaotic communications with correlator receivers: theory and performance limits," 2002.

[19] G. Kolumban and T. Krébesz, "UWB radio: A real chance for application of chaotic communications," Proc.NOLTA'06, pp. 475-478, 2006.

[20] Kennedy, Michael Peter, and Géza Kolumbán. "Digital communications using chaos." Signal processing 80.7 (2000): 1307-1320.

[21] F. C. Lau and K. T. Chi, Chaos-Based Digital Communication Systems: Operating Principles, Analysis Methods, and Performance Evaluation. Springer, 2003.

[22] H. Leung, H. Yu and K. Murali, "Ergodic chaos-based communication schemes," Physical Review E, vol. 66, pp. 036203, 2002.

[23] H. Leung, S. Shanmugam, N. Xie and S. Wang, "An ergodic approach for chaotic signal estimation at low SNR with application to ultra-wide-band communication," Signal Processing, IEEE Transactions on, vol. 54, pp. 1091-1103, 2006.

[24] Y. Liu, I. Elhanany and H. Qi, "An energy-efficient QoS-aware media access control protocol for wireless sensor networks," in Mobile Adhoc and Sensor Systems Conference, 2005, IEEE International Conference on, 2005, pp. 3 pp.-191

[25] M. Lujuan, "Hybrid DCSK/TDMA Multi-Rate MAC Protocol for Underwater Acoustic Sensor Networks," JDCTA: International Journal of Digital Content Technology and its Applications, vol. 6, pp. 565~ 572-565~ 572.

[26] S. Mandal and S. Banerjee, "Performance of differential chaos shift keying communication over multipath fading channels," in National Conference on Nonlinear Systems & Dynamics, 2002, pp. 1-4.

[27] F. Nekoogar, Ultra-Wideband Communications: Fundamentals and Applications. Prentice Hall Press, 2005.

[28] F. S. Netto and M. Eisencraft, "Spread spectrum digital communication system using chaotic pattern generator," in 10th Experimental Chaos Conference, Catania, 2008.

[29] N. Patwari, J. N. Ash, S. Kyperountas, A. O. Hero, R. L. Moses and N. S. Correal, "Locating the nodes: cooperative localization in wireless sensor networks," Signal Processing Magazine, IEEE, vol. 22, pp. 54-69, 2005.

[30] L. M. Pecora and T. L. Carroll, "Synchronization in chaotic systems," Phys. Rev. Lett., vol. 64, pp. 821-824, Feb 19, 1990.

[31] U. Pešović, J. Mohorko, K. Benkič and Ž. Čučej, "Effect of hidden nodes in IEEE 802.15. 4/ZigBee wireless sensor networks," in XVII Telecommunications Forum-TELFOR, 2009, pp. 24-26.

[32] J. G. Proakis, "Digital Communications Fourth Edition, 2001," 1998

[33] T. Rappaport, "Wireless Communications Principles and Practice Second Edition, 2002,"

[34] Z. Ren, G. Wang, Q. Chen and H. Li, "Modelling and simulation of Rayleigh fading, path loss, and shadowing fading for wireless mobile networks," Simulation Modelling Practice and Theory, vol. 19, pp. 626-637, 2011.

[35] J. Rice, "SeaWeb acoustic communication and navigation networks," in Proceedings of the International Conference on Underwater Acoustic Measurements: Technologies and Results, 2005.

[36] R. Rovatti, G. Mazzini and G. Setti, "Enhanced rake receivers for chaos-based DS-CDMA," Circuits and Systems I: Fundamental Theory and Applications, IEEE Transactions on, vol. 48, pp. 818-829, 2001.

[37] A. Savvides, H. Park and M. B. Srivastava, "The bits and flops of the n-hop multi alteration primitive for node localization problems," in Proceedings of the 1st ACM International Workshop on Wireless Sensor Networks and Applications, 2002, pp. 112-121

[38] N. Saxena, A. Roy and J. Shin, "Dynamic duty cycle and adaptive contention window based QoS-MAC protocol for wireless multimedia sensor networks," Computer Networks, vol. 52, pp. 2532-2542, 2008.

[39] R. Severino and M. Alves, "Engineering a search and rescue application with a wireless sensor network-based localization mechanism," in World of Wireless, Mobile and Multimedia Networks, 2007. WoWMoM 2007. IEEE International Symposium on a, 2007, pp. 1-4.

[40] E. M. Sozer, M. Stojanovic and J. G. Proakis, "Underwater acoustic networks," Oceanic Engineering, IEEE Journal of, vol. 25, pp. 72-83, 2000.

[41] E. M. Sozer, M. Stojanovic and J. G. Proakis, "Design and simulation of an underwater acoustic local area network," in Proc. Opnetwork'99, 1999, .

[42] R. D. Standfield, OPNET Implementation of Spread Spectrum Network for Voice and Data Distribution., 1997.

[43] M. Stojanovic, "On the relationship between capacity and distance in an underwater acoustic communication channel," ACM SIGMOBILE Mobile Computing and Communications Review, vol. 11, pp. 34-43, 2007

[44] M. Stojanovic, "Underwater acoustic communications," in Electro/95 International. Professional Program Proceedings, 1995, pp. 435-440.

[45] M. Sushchik, L. S. Tsimring and A. R. Volkovskii, "Performance analysis of correlation-based communication schemes utilizing chaos," Circuits and Systems I: Fundamental Theory and Applications, IEEE Transactions on, vol. 47, pp. 1684-1691, 2000.

[46] A. J. Viterbi, "Wireless digital communication: A view based on three lessons learned," IEEE Communications Magazine, vol. 29, pp. 33-36, 1991.

[47] M. C. Vuran and I. F. Akyildiz, "Cross-layer packet size optimization for wireless terrestrial, underwater, and underground sensor networks," in INFOCOM 2008, the 27th Conference on Computer Communications. IEEE, 2008