JCSE Journal of Computing Science and Engineering

Regular Paper
Journal of Computing Science and Engineering,
Vol. 6, No. 2, June 2012, pp. 119-126

Machine-to-Machine Communications for Healthcare

Kwang-Cheng Chen*
Graduate Institute of Communication Engineering, and Intel-NTU CCC Center, National Taiwan University, Taipei, Taiwan
chenkc@cc.ee.ntu.edu.tw

Abstract
Machine-to-machine communications for healthcare is emerging for the benefit of humans. In addition to novel medium access, we provide a systematic view to look for ways to develop technology to accomplish this goal, and a thorough vision toward effective system and network design.

Category: Smart and intelligent computing

Keywords: Machine-to-machine communications; Healthcare; Medium access; Cloud services

I. INTRODUCTION

The United States National Academy of Engineering listed 14 grand challenges in technology, most of them are related to environmental, health, or societal issues. To facilitate such technology, utilizing machines (or networked devices) to collect information and to infer decision and control through the Internet structure has attracted a lot of research interest. Similar concepts have been looked into recently, such as well known machine-to-machine (M2M) [1, 2], cyber physical systems (CPS) [3, 4], and Internet of Things (IoT) [5, 6].The fundamental idea behind these concepts is to extend human-to-human communication to machine/device interaction with persons/machines so that human life style can be enhanced using the Internet for the information infrastructure. The required autonomous operation in a self-organizing way may include service discovery, machine or smart device identification, data networking, resource/energy allocation, interaction among machines, recognition and decision/control or interaction with persons, etc. Although such a scenario involves information collection, processing or computing and communication and networking, this paper focuses more on information exchange and flow, that is, communications and networks, for future Internet applications.

Among so many potential applications, applying machines (likely sensors) to healthcare has attracted a tremendous amount of research interest in recent years in our aging society [1-7]. Future healthcare relies on medical devices and systems (i.e., organizing machines) that are networked to ubiquitously match the need of patients in special circumstances. Such healthcare systems enable intelligent hospitals, guided surgery and therapy as well as seamless control of medical and biological treatments. M2M communication for healthcare relies on sensors to form a body (or personal) area network, which can be traced back to T. G. Zimmerman's master's thesis at Massachusetts Institute of Technology (MIT) in 1995, to enable intra-body communications. This idea was further fertilized by the wearable technology developed at MIT Media Laboratory for healthcare sensors [8] and even in fabric garment without any cable [9], to facilitate unlimited imagination healthcare, and to create a new dimension in networking challenges. In the early 21st century, IEEE project 802 standardized wireless personal area net-

Open Access http://dx.doi.org/10.5626/JCSE.2012.6.2.119 http://jcse.kiise.org

Received 10 August 2011, **Revised** 1 January 2012, **Accepted** 3 May 2012
*Corresponding Author

† This paper is part of the special issue on uHealthcare published at JCSE vol.6, no.1 in March, 2012.

pISSN: 1976-4677 eISSN: 2093-8020

works (WPAN) and thus wireless body area networks (WBAN), under the umbrella of IEEE 802.15. Many healthcare systems adopt 802.15 WPAN, 802.11 WLAN, or Zigbee [7, 10-14], leveraging their different transmission characteristics and data rates. However, regarding M2M communication to support healthcare, existing research looks more at system integration of available devices to a central system. The communication network design while there exists a tremendous number of machines is not often looked at. In this paper, we would like to explore the fundamental networking behaviors of M2M communications for healthcare, which has seldom been discussed in literature. We may note research and technology opportunities arise from such new networking challenges, such that further M2M communication technology that can benefit healthcare systems and thus human beings.

This paper is organized as follows. We summarize system models and myths in M2M communication for healthcare in Section II. We then develop the network theoretical model using graph theory and thus potentially a practical solution for medium access in Section III. Various important M2M networking control functions are investigated in Section IV, including further graph theoretical technique, network synchronization, quality of service (QoS), interference control, energy efficiency and security.

II. SYSTEM MODELS AND MYTHS

As stated in various literatures, emerging WBAN is likely to be adopted in healthcare systems. A WBAN usually consists of a number of machines (typically sensors), while each machine can measure and sample physiological information such as heart rate, blood pressure, body temperature, etc. and environment information such as humidity, temperature, sun light, etc. Each machine has a way to transmit information to a data aggregator (or to the infrastructure directly, say to a base station or gateway to the cloud). The final target is to transport information from machines/sensors to the medical center for in-time appropriate decisions and actions, and possibly transport control messages in the reverse direction.

A. System Architecture of M2M Communications for Healthcare

As in the general architecture of [1], we show the system architecture of M2M communication for healthcare in Fig. 1. Cellular type wireless systems such as 3rd generation partnership project (3GPP) long-term evolution (LTE) or LTE-advanced, and the Internet (i.e., cloud computing), serve as the M2M communication infrastructure for healthcare. The medical center can collect related information from the networked cloud and instruct machines in the reverse direction, as a bi-directional communication network. In Fig. 1, the curve dot lines represent links of a cellular type system and the solid black lines represent Internet access links as a part of a cloud. 3GPP currently is making a serious effort for machine-type communication (MTC) [2], and healthcare is one of the major applications.

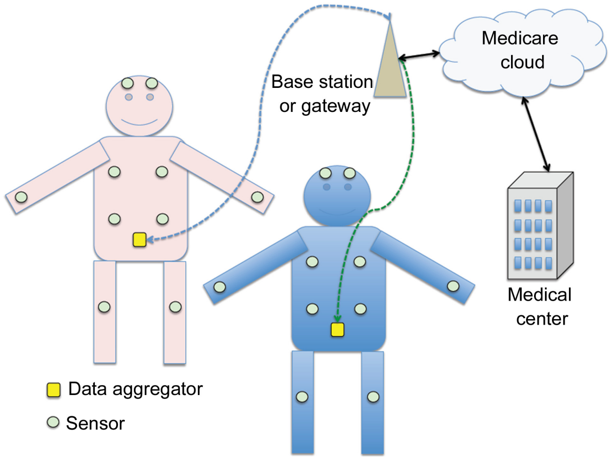

Fig. 1. System architecture of machine-to-machine communications for healthcare.

The remaining part of the system architecture relates to communication and networking from machines/sensors to data aggregator. It is usually referred as the local network in M2M communications. Sometimes, such communication is known as communication for the "swarm" in cyber physical systems, which suggests a huge number of machines in the system. This scenario, although it looks simple, is actually very challenging as there may be trillions devices in this scenario, migrating from billions of devices for wireless personal communications in past decades. Since the frequency bands lower than a few GHz enjoy nice radio propagation and cost-effective semiconductor fabrication, such frequency bands are very much preferred by M2M communications, particularly for healthcare. In addition to current wireless personal communications operating in this frequency range, the very limited available spectrum has to support a good portion of these trillions devices. Spectrum efficient communication and networking technologies are vital, while energy efficiency has to be satisfied as most machines/sensors are operating by battery. In addition to the critical spectrum efficiency and energy efficiency problems, M2M communications faces the following technology challenges:

- Large and dense networks: There should be trillions devices in M2M, a big jump from the billions devices of today's wireless personal communications. Consequently, the limiting behaviors of large and/or dense wireless networks plays an important role, especially if there is a limited amount of available spectrum.
- Scalability: To effectively serve diverse application scenarios, M2M communications must be able to

meet the requirement of scalability, with a potentially significant dynamic number of devices to serve.
- Heterogeneity: Again, diverse application scenarios and thus communication scenarios require heterogeneous wireless networks to support and operate. For example, some M2M applications require long-range communications with infrastructure and dedicated spectrum, while some applications prefer short-range communications in a spectrum sharing ad hoc mode. For healthcare application scenario, different systems may co-exist as persons' movement as a new cause for heterogeneity.

Furthermore, services and applications on top of such physical systems would be the core values of M2M communication for healthcare. Real-time autonomous services also introduce technological challenges in security, privacy, and interoperability etc.

B. Myths in M2M Communications for Healthcare

Typical M2M communications or sensor networks assume the following: 1) the networking nodes (i.e., machines or sensors) do not move, 2) the traffic volume of M2M communications for each purpose is low, with a small duty cycle.

However, these assumptions do not hold in healthcare application scenarios. Fig. 1 depicts the M2M networking structure for healthcare. We can note the special features of M2M for healthcare, in terms of network topology. Since many sensors are installed according to the human body, the locations of these sensors/machines can actually move, due to human movement. In other words, locations of sensors relative to the data aggregator (DA) may vary, while the data aggregator may also move according to human movement. Consequently, the machines are not static at all, which is similar to networking among robots. This is exactly like mobile networks. The immediate question to our minds would be "what does the channel model look like?" as this heavily impacts network topology and thus system/network design. The 400 MHz, 600 MHz, 900 MHz, and 2.4 GHz channels were studied by attaching sensors to different parts of the body and it was found that by simply modifying some parameters of the popular log-normal channel model in mobile communications we still apply this model in such a scenario [15]. Generally speaking, once we have to deal with mobility, a two-tier or multi-tier network structure is likely to be employed to serve nodes with different ranges and mobility.

The next issue is the assumption of low traffic volume. Table 1 presents common physiological parameters in healthcare. Each sample might be small in size. However, due to the need for constant monitoring, the sampling frequency is usually not low, and thus the net data rate for each parameter is not low either. If we further consider the overall data rate of these parameters from each person to the data center, we are talking of a rate similar to a mobile video stream, higher than the traffic of a handset in mobile cellular communications, and a stream that is constantly on 24 hours a day and 365 days a year. If such healthcare applies to a good portion of population, we are facing a bandwidth hungry situation in communications and networks.

After understanding the truth behind these common myths, to develop solutions to the above-mentioned challenges in terms of spectrum-efficient and energy-efficient autonomous reconfigurable connectivity supporting density, mobility, configurability, will allow us to supply the M2M local network enabling healthcare applications and services.

C. Spectrum Sharing and Interference

To serve multiple communication scopes, such as different ranges and different data rates, adopting heterogeneous wireless networks, even in the same frequency band [10, 11], is common in M2M communications for healthcare [16]. This introduces a new challenge to autonomously control the configurability of the local network. Please also recall that earlier heterogeneity further induces another communication challenges: spectrum sharing among heterogeneous wireless networks. As human-to-human (H2H) wireless personal communications shall occupy even more spectrum in the future, it is obvious that M2M communications are unlikely to have enough dedicated frequency bandwidth. Under these circumstances, spectrum sharing wireless networking is the only

Table 1. Data characteristics of some physiological measurements [11]

Parameter	Sampling frequency	Bits per sample	No. of channels	Data rate (bps)
Electroencephalogram	256-512 Hz	16	8-128	32,768-1,048,576
Electrocardiography	200 Hz	16	1-3	3,200-9,600
Blood pressure	120 Hz	16	1	1,920
Pulse oximeter	60	16	2	1,920
Cardiac output	40	16	1	640
Body temperature	0.2 Hz	12	1	2.4

feasible technology trend.

In case there exists a wireless network that has priority to use the spectrum (say, a H2H system) in spectrum sharing wireless networks, we call that network the primary system (PS). The nodes of other wireless networks can dynamically access the spectrum only if there exists transmission opportunities (i.e., nodes in the PS are not in transmission) as secondary users of the spectrum. We call such secondary nodes cognitive radios (CRs) [17, 18], which is a popular research subject to achieve spectrum efficiency nowadays. CR technology is promising for M2M local networks. Another case is multiple wireless networks sharing the spectrum, which is known as a heterogeneous wireless networks. The interference and its impacts on networking is still an open research topic, particularly for multi-hop ad hoc networks. [18, 19] summarize techniques that mitigate interference.

III. DESIGN OF LOCAL NETWORKS

Examining Fig. 1, we may apply graph theory to the model of the local network in M2M communications for healthcare. Using such graphs, we may precede in a fruitful networking study about local network design for M2M communications.

A. Graph Theoretical Model of Local Networks

As seen in Fig. 1, the local network serves the purpose of transporting data between machines/sensors and the data aggregator. Please recall that both spectrum efficiency and energy efficiency suggests a small communication range for M2M communication, which has the added benefit of low-radiation to human bodies. Considering this factor, multi-hop ad hoc networking shall be adopted in M2M communications for healthcare as shown in Fig. 2. Each machine shall have the capability of store and forward, in order to implement cooperative relay in multi-hop ad hoc networking, using amplify-and-forward or decode-and-forward strategies. Each machine may be able to encode forwarded message and their own

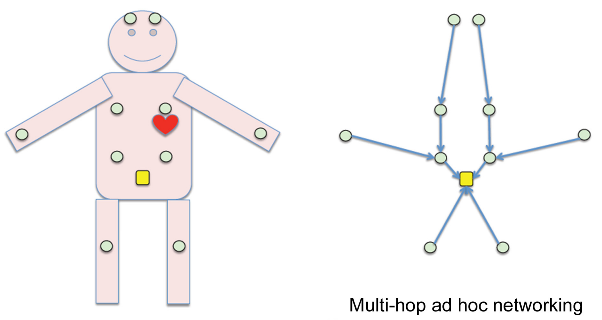

Fig. 2. Multi-hop ad hoc networking for machines.

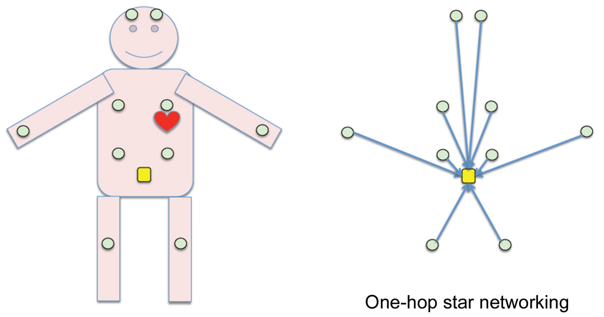

Fig. 3. Medium access to data aggregator.

message together, which is known as a compress-and-forward strategy in cooperative communications. If we further consider spectrum sharing such as cognitive radio networks (CRN), it is still rather an open subject, [18] provides a detailed overview.

As the body area is not large, one-hop from the machines/sensors to data aggregator in a local network is attractive too. Fig. 3 illustrates this star-topology. This is exactly the same as medium access control (MAC) in typical local area networks (LANs). The general principles of MAC in wireless local area networks can be found in [20]. Subsequent efforts give a generalized tree-protocol [21] that can be tailored for different operating conditions and environments to yield maximum throughput performance and even energy efficiency [22].

B. Hoffman Coded Medium Access of Local Network

The challenges of random/multiple access in M2M networking lie in the following:

1) An extremely large number of nodes, which have strict energy or battery efficiency requirements for operational purpose. This also implies communication and networking overheads that create significant loss of throughput, and as such is slightly different from traditional medium access problems.
2) Limited available spectrum, in spite of the tremendous amount of devices (i.e., nodes)
3) Extremely low duty cycle in traffic patterns for each device
4) Device manageability [3], which allows gateways or data aggregators to detect malfunction devices and to manage efficient networking. This is essential in the successful M2M networking, as a certain percentage of devices will likely fail after a period of time.

It is well known that both carrier sensing and collision detection can facilitate medium access, according to Gallager's pioneer paper in 1985 *IEEE Transactions on Information Theory* [23]. The generalized tree structure was introduced to model random/multiple access protocols [21]. To reduce overhead for energy/battery efficiency, it is preferred both mechanisms are not used, which likely allows very light operations using carrier sensing and collision detection. Failure nodes and deployment of heterogeneous sensors/devices prohibit centralized medium access, and random access has to be used.

As energy/power consumption plays a critical role, we may categorize the energy consumption of each successful collected data transmission/message into

- Sensing power (at sensor node only)
- Packet transmission including header (at sensor node only)
- Retransmission including collision resolution and possible automatic repeat request (at both data aggregator and sensor node)
- Processing power including radio frequency and baseband circuit processing and software processing (at sensor node only)

While traditional random/multiple access consists of a 3-state transition diagram (i.e., receive-state, transmit-state and sensing-state), the optimization of random/multiple access becomes a multi-objective problem when simultaneously considering maximization of throughput and minimization of node access energy.

To precede the design of medium access, we have the following assumptions:

- There exists special physical layer signaling, typically a unique word, to awake selected devices.
- Each data aggregator can have “some” knowledge about sensors that it collects data from. In other words, the total traffic load from each round of data collection is known through some certain update mechanism.
- Each sensor node has similar propagation delay to the data aggregator and also a similar received signal power, which suggests no near-far problem nor capture effect at the physical layer.

To meet these challenges, we reach the following conclusions:

- To save energy/power, sensing shall be avoided if possible
- To save energy/power and to enhance throughput, collisions shall be avoided and collision resolution shall be minimized
- The overhead to transmit data to the data aggregator shall be minimized and constrained to the need of physical layer transmission only. That is, the overhead due to network control operation should be minimized or, preferably zero.
- However, device manageability (K. Johnson, Intel Co., private communications) to detect malfunctioning nodes/sensors should be included.

Hoffman coding is a well-known source coding technique that satisfies the prefix condition while *a prior* distribution of alphabets is available. The similarity of source coding and data collection suggests that we adopt the same concept for multiple accesses, based on data traffic load.

We construct a super-frame structure starting with a unique word (UW) and total of N slots tofollow the UW. Each slot accommodates transmission of a data frame. Suppose there are K nodes/sensors where the data aggregator wants to collect data. The k^{th} node/sensor has l_k data frames/packets to transmit. In other words, the data aggregator has to collect a total of

$$L = \sum_{k=1}^{K} l_k$$

data frames/packets. We define $p_k = l_k/L$ as a sort of *a prior* probability. We can construct a set of Hoffman codes, similar to the spreading code generation of orthogonal variable spreading factor (OVSF) in multi-rate code-division multiple access (CDMA), based on $\{p_k\}$. The k^{th} node/sensor consequently obtains a Hoffman code, c_k, from the data aggregator.

The proposed Hoffman coded medium access control (HC-MAC) operates as follows:

- When the data aggregator intends to collect data from its group of nodes/sensors, a specified UW is broadcast. This UW can trigger the front circuits to awake communication function of all nodes/sensors, and thus set up a temporary counter from 1 to L.
- Based on $\{c_k\}$ and the temporary counter, when the counter matches c_k, the k^{th} node/sensor transmits the data/information. Then, the k^{th} node/sensor turns off.
- Repeat until counter reaching L.

For each node/sensor, the energy for communication in each transmission only consists of the front-end UW detection, counter operation, overhead for each data frame/packet and transmission of the data frame(s). It obviously reaches the maximal possible throughput and energy efficiency.

On the other hand, if there exists any malfunctioning nodes/sensors, the data aggregator may observe a null transmission slot(s). Update at the data aggregator can be facilitated as follows. When a malfunction node(s) is detected, the data aggregator may amend the HC-MAC during the control period, which can be in the $(L + 1)^{\text{th}}$ slot andwould be triggered by another pre-selected UW.

The same principle can be further generalized into large-scale operation and fine information quantity into bits. For more realistic system implementation, [24] provides update detailed discussions.

IV. NETWORK CONTROL FUNCTIONS

To completely implement M2M communication for healthcare, there are some more important issues to consider.

A. Graph Rigidity

Up to this moment, research in literature primarily deals with a rather static network topology. However, in Fig. 2 or Fig. 3, the positions of machines/sensors would actually be changing due to body movement and human mobility. As such, we adopt the concept of graph rigidity that studies formation graphs allowing permissible motions while maintaining appropriate edge distances. Following this concept, we call a trajectory “rigid” if the distances between each pair of adjacent nodes and their states remain constants. Therefore, a rigid trajectory represents a rigid motion of the network, starting from the formation during which the distances of all machines are maintained [25]. Shape based control can be thus defined and developed, including in multi-hop ad hoc networking among a dense population that implies potentially severe interference from other local networks of individuals.

B. Time Synchronization

Many network protocols of M2M communications such as [26] assume time slotted operations. However, local networks of individuals in a dense population may suffer sever interference, and thus timing alignment among heterogeneous wireless networks may suffer. Generally speaking, this might lead to a chaotic system. Proper time synchronization among such networks is very important, it may be achieved through synchronization of infrastructure such as in cellular type systems.

C. Quality of Services and Context-Aware Techniques

It is usually assumed that M2M communications do not require QoS as end-to-end latency can be tolerated. For healthcare applications, this is unfortunately not true since many physiological parameters are extremely time sensitive. We can utilize context aware techniques to improve QoS [27], or design tradeoffs with memory [28] to reach the goals of QoS. Information driven technology is now being considered in the Intel-NTU CCC Center to provide a performance benchmark.

D. Interference Control and Mitigation

As a matter of fact, healthcare applications are sensitive to interference. However, in large scale and dense operation of M2M communication, this is an overlooked technology in regard to heterogeneous wireless networks. Some in-depth studies are available in [16-19].

E. Energy Efficiency

Energy efficiency is always important in M2M communication. A typical study that looks at energy efficiency in medium access control is [22], and one with a focus on healthcare scenarios is [29]. What the best strategy for multi-hop local networks and entire end-to-end systems is not clear now. According to [30], M2M for healthcare is a sort of cloud computing, and effective use of radios in local networks, including leverage machines’ radio waiting duration for cooperative relay, can help from the entire system point of view.

F. Security and Privacy

Healthcare applications of M2M might be most sensitive to privacy and security. Great attention to this subject has been paid, such as in [31], and even more attention has been given to M2M communications, cyber physical systems, and the Internet of Things. Security can be achieved by heavy computation, and proper management of communications and computations may yield satisfactory system tradeoffs. Privacy in transporting sensitive data and inference from such data is rather unique in healthcare in such an autonomous communication scenario. Under mobile application scenario, a secure and privacy preserving framework for healthcare has been proposed by leveraging smart phones [32].

V. CONCLUSIONS

This paper examines M2M communications for healthcare in a systematic way, considering new medium access for device manageability. We do not expect this paper to present a final solution for technology in this field. Instead, we expect it to open a new discussion that will lead to the development of this important technology that benefits human beings.

ACKNOWLEDGMENTS

This research is supported by the National Science Council, Intel Co., and National Taiwan University, under the contract NSC 99-2911-I-002-201.

REFERENCES

1. G. Wu, S. Talwar, K. Johnsson, N. Himayat, and K. D. Johnson, “M2M: from mobile to embedded internet,” *IEEE Communications Magazine*, vol. 49, no. 4, pp. 36-43, 2011.
2. S. Y. Lien, K. C. Chen, and Y. Lin, “Toward ubiquitous massive accesses in 3GPP machine-to-machine communications,” *IEEE Communications Magazine*, vol. 49, no. 4, pp. 66-74, 2011.
3. E. A. Lee, “Cyber physical systems: design challenges,” *Proceedings of the 11th IEEE Symposium on Object Oriented Real-Time Distributed Computing*, Orlando, FL, 2008, pp. 363-369.

4. R. Rajkumar, I. Lee, L. Sha, and J. Stankovic, “Cyber-physical systems: the next computing revolution,” *Proceedings of the 47th Design Automation Conference*, Anaheim, CA, 2010, pp. 731-736.
5. L. Atzori, A. Iera, and G. Morabito, “The internet of things: a survey,” *Computer Networks*, vol. 54, no. 15, pp. 2787-2805, 2010.
6. M. Kranz, P. Holleis, and A. Schmidt, “Embedded interaction: interacting with the internet of things,” *IEEE Internet Computing*, vol. 14, no. 2, pp. 46-53, 2010.
7. H. Alemdar and C. Ersoy, “Wireless sensor networks for healthcare: a survey,” *Computer Networks*, vol. 54, no. 15, pp. 2688-2710, 2010.
8. A. Pentland, “healthwear: medical technology becomes wearable,” *Computer*, vol. 37, no. 5, pp. 42-49, 2004.
9. E. Wade and H. Asada, “Conductive fabric garment for a cable-free body area network,” *IEEE Pervasive Computing*, vol. 6, no. 1, pp. 52-58, 2007.
10. J. M. Corchado, J. Bajo, D. I. Tapia, and A. Abraham, “Using heterogeneous wireless sensor networks in a telemonitoring system for healthcare,” *IEEE Transactions on Information Technology in Biomedicine*, vol. 14, no. 2, pp. 234-240, 2010.
11. J. Misic and V. Misic, “Bridging between IEEE 802.15.4 and IEEE 802.11b networks for multiparameter healthcare sensing,” *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 4, pp. 435-449, 2009.
12. F. Chiti, R. Fantacci, F. Archetti, E. Messina, and D. Toscani, “An integrated communications framework for context aware continuous monitoring with body sensor networks,” *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 4, pp. 379-386, 2009.
13. T. Taleb, D. Bottazzi, M. Guizani, and H. Nait-Charif, “ANGELAH: a framework for assisting elders at home,” *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 4, pp. 480-494, 2009.
14. C. Otto, A. Milenkovic, C. Sanders, and E. Javanov, “System architecture of a wireless body area sensor network for ubiquitous health monitoring,” *Journal of Mobile Multimedia*, vol. 1, no. 4, pp. 307-326, 2005.
15. N. Katayama, K, Takizawa, T. Aoyagi, J. I. Takada, H. B. Li, and R. Kohno, “Channel model on various frequency bands for wearable body area network,” *IEICE Transactions on Communications*, vol. E92-B, no. 2, pp. 418-424, 2009.
16. D. Niyato, E. Hossain, and S. Camorlinga, “Remote patient monitoring service using heterogeneous wireless access networks: architecture and optimization,” *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 4, pp. 412-423, 2009.
17. K. C. Chen and R. Prasad, Cognitive Radio Networks, Chichester, UK: Wiley, 2009.
18. Y. C. Liang, K. C. Chen, G. Y. Li, and P. Mahonen, “Cognitive radio networking and communications: an overview,” *IEEE Transactions on Vehicular Technology*, vol. 60, no. 7, pp. 3386-3407, 2011.
19. S. M. Cheng, S. Y. Lien, F. S. Chu, and K. C. Chen, “On exploiting cognitive radio to mitigate interference in macro/femto heterogeneous networks,” *IEEE Wireless Communications*, vol. 18, no. 3, pp. 40-47, 2011.
20. K. C. Chen, “Medium access control of wireless LANs for mobile computing,” *IEEE Network*, vol. 8, no. 5, pp. 50-63, 1994.
21. Y. K. Sun, K. C. Chen, and D. C. Twu, “Generalized tree multiple access protocols in packet switching networks,” *The 8th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, Helsinki, Finland, 1997, pp. 918-922.
22. Y. K. Sun and K. C. Chen, “Energy-efficient multiple access protocol design,” *IEEE Communications Letters*, vol. 2, no. 12, pp. 334-336, 1998.
23. R. G. Gallager, “A perspective on multi-access channels,” *IEEE Transactions on Information Theory*, vol. 31, no. 2, pp. 124-142, 1985.
24. A Bolis, D. Smith, D. Miniutti, L. Libman, and Y. Tselishchev, “Challenges in body area networks for healthcare: the MAC,” *IEEE Communications Magazine*, vol. 50, no. 5, pp. 100-106, 2012.
25. M. Mesbahi and M. Egerstedt, *Graph Theoretic Methods in Multiagent Networks*, Princeton, NJ: Princeton University Press, 2010.
26. H. Su and X. Zhang, “Battery-dynamics driven TDMA MAC protocols for wireless body-area monitoring networks in healthcare applications,” *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 4, pp. 424-434, 2009.
27. F. Hu, Y. Xiao, and Q. Hao, “Congestion-aware, loss-resilient bio-monitoring sensor networking for mobile health applications,” *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 4, pp. 450-465, 2009.
28. N. Xiong, A. V. Vasilakos, L. T. Yang, L. Song, Y. Pan, R. Kannan, and Y. Li, “Comparative analysis of quality of service and memory usage for adaptive failure detectors in healthcare systems,” *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 4, pp. 495-509, 2009.
29. B. Otal, L. Alonso, and C. Verikoukis, “Highly reliable energy-saving MAC for wireless body sensor networks in healthcare systems,” *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 4, pp. 553-565, 2009.
30. F. S. Chu, K. C. Chen, and C. M. Cheng, “Toward green cloud computing,” *Proceedings of the 5th International Conference on Ubiquitous Information Management and Communication*, Seoul, Korea, 2011, article no. 31.
31. X. Lin, R. Lu, X. Shen, Y. Nemoto, and N. Kato, “SAGE: a strong privacy-preserving scheme against global eavesdropping for ehealth systems,” *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 4, pp. 365-378, 2009.
32. R. Lu, X. Lin, and X. Shen, “SPOC: a secure and privacy-preserving opportunistic computing framework for mobile-healthcare emergency,” *IEEE Transactions on Parallel and Distributed Systems*, 2012. Early access article.

Kwang-Cheng Chen

Kwang-Cheng Chen received a B.S. from National Taiwan University in 1983, a M.S. and Ph.D from the University of Maryland, College Park, United States, in 1987 and 1989, all in electrical engineering. From 1987 to 1998, Dr. Chen worked at SSE, COMSAT, the IBM Thomas J. Watson Research Center and National Tsing Hua University, in mobile communications and networks. Since 1998, Dr. Chen has been with National Taiwan University, Taipei, Taiwan, ROC and is the *Distinguished Professor* and *Director* of the Graduate Institute of Communication Engineering. He is also the *Director* of the Communication Research Center at the National Taiwan University. Dr. Chen is actively involved in the technical organization of numerous leading IEEE conferences, including as the Technical Program Committee Chair of the *1996 IEEE International Symposium on Personal Indoor Mobile Radio Communications*, TPC co-chair for IEEE Globecom 2002, General Co-Chair for 2007 IEEE Mobile WiMAX Symposium in Orlando, 2009 IEEE Mobile WiMAX Symposium in Napa Valley, IEEE 2010 Spring Vehicular Technology Conference and IEEE 2011 IEEE Online Conference in Green Communications. He has served editorship with many IEEE journals and international journals and has held various positions in IEEE. Dr. Chen also actively participates in forming various wireless international standards. He has authored and co-authored over 200 technical papers and has been granted 20 US patents. He co-edited (with R. De Marca) the book *Mobile WiMAX* published by Wiley in 2008, authored the book *Principles of Communications* published by River in 2009 and co-authored (with R. Prasad) another book *Cognitive Radio Networks* published by Wiley in 2009. Dr. Chen is an *IEEE Fellow* and has received a number of awards including the *2011 IEEE Communications Society Wireless Communications Recognition Award* and co-authored the 2010 *IEEE ICC Best Paper* and *IEEE GLOBECOM GOLD Best Paper*. Dr. Chen's research interests include wireless communications and network science.