Ubiquitous Healthcare for Environmentally Linked Disease Syndromic Surveillance

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***Abstract*— Ubiquitous Healthcare utilizes an array of small low-power environmental sensors for prognosis and diagnosis of health degradation. By focusing on condition-based monitoring of patient behavior and the ambient environment assessment, this paper presents a framework for syndromic surveillance of chronic disease with an emphasis on asthma and control using ubiquitous telemedicine solution. This allows regulation of indoor air quality for a healthy living environment for active prevention and provides a framework for automatic update of electronic patient record. Upon detection of any abnormality, the system can also trigger an alert for immediate medical attention to be provided.**

Keywords*- *Chronic disease prevention, environmental health, telemedicine, ubiquitous healthcare

I. Introduction

Ubiquitous healthcare provides a wide range of services to patients with different needs. A range of bio and environmental sensors can be connected to a remote server for disease surveillance and update of electronic patient record (EPR) [1]. The concept of ubiquitous e-health as used for different applications throughout the world relies on three fundamental elements, namely contents of the medical information for both patients and healthcare professionals; connectivity for communication, ease of sharing information, and for providing swift response in the event of an acute situation; and business for product and service development [2]. By connecting patients and their caregivers together through wireless telemedicine networks, patients suffering from different types of diseases can be taken cared of anytime anywhere. Since chronic disease usually requires long-term continual monitoring for symptoms and health degradation [3], a low-cost surveillance solution that offers a high degree of mobility would assist with provide early treatment and reduce the number of clinic visits.

Through development of a body area network (BAN) different types of wearable sensors can be attached to a patient that monitors the patient's physiological signs and the surrounding environment, any contributing factors that worsen the symptoms of asthma can be detected Environmental monitoring is important for active prevention since asthma patients often react to a range of pollutants in the inhaled air that irritate the airways of the respiratory system [4].

Ubiquitous healthcare for asthma patients is an important topic since 10% of Americans are reported to be asthma sufferers according to the US Centers for Disease Control and Prevention (CDC) statistics [5]. Air pollution is a well known trigger for asthma symptoms. Indoor air pollution is becoming a serious health issue as a range of chemicals such as acid aerosols and volatile organic compounds (VOCs) can trigger asthma symptoms [6]. The biosensors need to measure and record a patient's peak flow breathing for refractory asthma management. Improving indoor air quality by reducing indoor particulate pollutant concentrations will provide a vital means of improving asthma patients' health. Reduction of respiratory health risk to asthma patients through ubiquitous healthcare entails a series of longitudinal health data to be coupled with detailed monitoring of personal exposure is necessary such that an accurate estimation of the exposure-response relation for air pollutants from various sources can be established.

II. Motivation and Problem Overview

Among environmentally-linked chronic diseases, asthma alone contributes to over 13 million ambulatory care cases annually for outpatients with asthma as primary diagnosis and hospitalization of almost half a million cases with an average length of stay of three and a half days [7]. Many of these cases would have been avoidable if appropriate actions were made to prevent asthma symptoms from being triggered. A healthier living environment to reduce asthma symptoms can be provided by ubiquitous healthcare solutions in monitoring environmental pollutions. Wireless sensor networks provide a range of solutions for monitoring different sources of pollutions in the patient's home by monitoring any changes in concentration of various pollutants [8].

To thoroughly address this problem, the first necessary step is to provide swift response to a patient when the disease symptoms are triggered. This is particularly challenging in rural areas where a lack of skilled healthcare professionals can be an issue as the nearest major hospital can be hundreds of

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miles away. Telemedicine system that supports remote camera control with a stethoscope for remote auscultation implemented for this purpose [9]. The stethoscope installed at the patient's home would allow a remote respiratory therapist to hear the heart tones and oscillations while simultaneously controlling the camera to see the patient.

III. Methodology and System Description

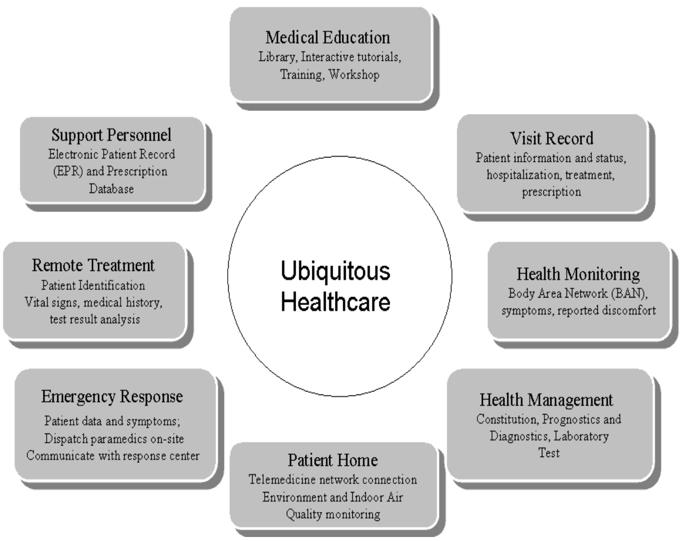

Fig. 1 Ubiquitous healthcare framework

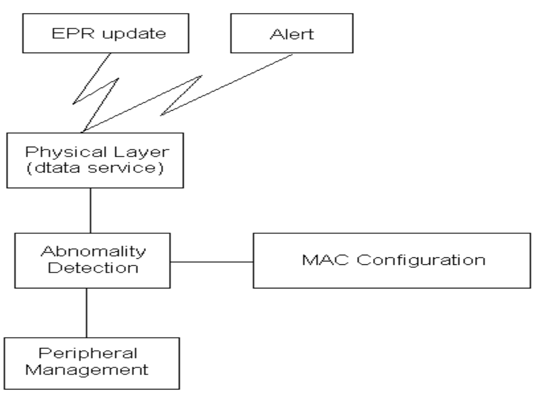

Fig. 2 Driver design

Fig. 1 shows a ubiquitous healthcare framework that supports round-the-clock syndromic surveillance with ambient environment sensing. A number of biosensors are installed in a body area network (BAN) around the patient's body and interconnected using the methodology described in [10] and connected to a 17 GHz wireless telemedicine backbone presented in [11] with the driver shown in Fig. 2. This driver controls real-time communication for use on a Bluetooth platform. Data packets are transmitted using IEEE 802.15.4 standard radio and uses a TCP send buffer via any 3G enabled smartphone. The data packets are received by a remote server for analysis and storage in the user's EPR.

The system consist of a body area network, environmental sensors, a telemedicine network and a remote server as shown in Fig. 3. The remote server, located in a clinic, can also be connected to other medical service centers and allows access to the user's EPR. This eHealth system relies on sensors and wireless networks that connect the sensors together. Data acquisition is an important part of the system and often requires the use of sensor systems to measure environmental and operational parameters. Wireless sensor networks provide a range of solutions for monitoring different sources of pollutions from the air we breathe to the water we drink. Different sensors exist for different applications. In this system where the physical state of the user and the surrounding environment is monitored, sensors are broadly classified into three major groups, namely physical, chemical, and biological [12]. The parameters which are to be monitored in the environment as well as human health can be selected based on their relationship to functions that are vital to the operating conditions, where it is possible to be implicated in an elevated risk of developing a health problem or trigger a symptom of an existing condition. Selection criteria are usually based on knowledge of the critical parameters established by the ambient environment and medical history of the patient. Sensing of multiple parameters can be accomplished using one single sensor system that can measure multiple types of parameters such as temperature, humidity, air pollution, and toxins. Systems that can realize multiple sensing include a sensor array which contains several different sensing elements internally; a sensor system can also include external ports for additional sensors to be attached such that it can support a combination of various sensor nodes. Physical attributes of a sensor includes its physical size, form factor, weight, case or housing, as well as how it is mounted to their environment.

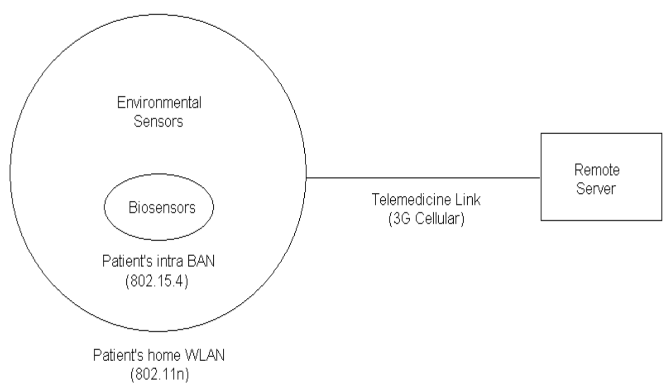

Fig. 3 Sensors network

A reliable communication network is essential to the successful deployment of ubiquitous healthcare. The network backbone is supported by a fixed WiMAX network that provides broadband distribution services in urban environments as last mile access for a diverse range of applications with carrier frequencies in excess of 10 GHz [13]. There are a number of issues that have to be considered when designing a WiMAX system in the frequency range spanning from 10 to 66 GHz. At these frequencies, multipath does not have any significant impact since high gain antennas with narrow beamwidth can be used for short paths [14]. System performance is greatly affected by link availability under various atmospheric conditions. Also, line-of-sight (LOS) or near line-of-sight is normally necessary between antennas. The selection of carrier frequency depends primarily on spectrum allocation by local authorities and operational conditions; the choice of operating frequency is also determined by population density and rainfall statistics.

WiMAX offers a more economical alternative to wired networks in many point-to-multipoint scenarios. However, data transfer is carried out in a very harsh environment subject to numerous causes of signal degradation and atmospheric phenomena; these include interference, rain-induced attenuation, and depolarization. Frequency planning for an allocated spectrum uses multiple sector systems with each sector supported by a base station of the access service network (ASN) serving a cell site. Uncontrollable factors such as rain-induced attenuation and depolarization must be considered to ensure adequate network availability.

Similar to passive optical networks (PONs), fixed WiMAX exhibit characteristics of point-to-multipoint topology [15]. In this context, network optimization can be realized through deployment of scheme comparable to cascaded arrayed waveguide gratings (AWGs) due to their cyclic property [16]. Both WiMAX and PON share the same topology given a fixed routing such that the position and placement of subscriber nodes can be optimized in much the same way as the cascaded AWG structure in PONs so as to optimize how much bandwidth each subscriber can receive. Redundancy is often required in a tree topology to combat the occurrence of link outage that can be addressed by the reliable scheme in [17]. By using this scheme, we evaluate the average packet delivery rate with each node broadcasting 250 packets per minute of 1 KB size, as shown in Fig. 5. The fraction of each packet successfully received shows different delivery rates.

IV. SYNDROMIC SURVEILLANCE

The main objective of disease syndromic surveillance is to detect disease outbreaks in anticipation of change of environment. Such early detection can be accomplished by monitoring data that are related to the outbreak, such as influenza-like illness (ILI) symptoms, over-the-counter (OTC) drug sales, hospital telephone calls, emergency admissions, and various forms of internet activity. By monitoring various disease-related indicators, an outbreak can be detected early so that countermeasures will be implemented effectively and proactively. The importance of early detection not only provides vital information for disease control, for asthma patients this can also provide additional time for taking any necessary precautionary measurements to reduce the risk of causing any complication.

The parameters used as precursors and the parameters monitored for disease syndromic surveillance in the context of environmental health requires careful selection of the location and frequency of measurement. These parameters can be measured by appropriate sensors. Disease surveillance requires integration of many different parameters to assess the health of patients who exhibit a certain symptom, either suspected or confirmed cases, and predict the spread pattern over time. If an individual sensor system can monitor multiple parameters, it will simplify the surveillance process. Sensing of multiple parameters refers to one sensor system that can measure multiple types of parameters such as temperature, humidity, pathogen and outbreak reports. Structures that can realize multiple sensing include a sensor system which contains several different sensing elements internally; a sensor system which has flexible, add-on external ports that support various sensor nodes. Onboard processing significantly reduces the number of data points and therefore can speed up the tracking of disease outbreaks. This in turn reduces the volume of data which must be transmitted for analysis and hence results in faster detection of disease occurrence. In the case of a large number of sensor systems working in the ubiquitous healthcare network, this would allow decentralization of monitoring and facilitate efficient parallel processing of outbreak data. Embedding computational power with onboard processors can also facilitate efficient data analysis for environmental monitoring applications. Embedded computations can be set to provide real-time updates for taking swift quarantine action, this is to efficiently reduce the risk of further disease spread.

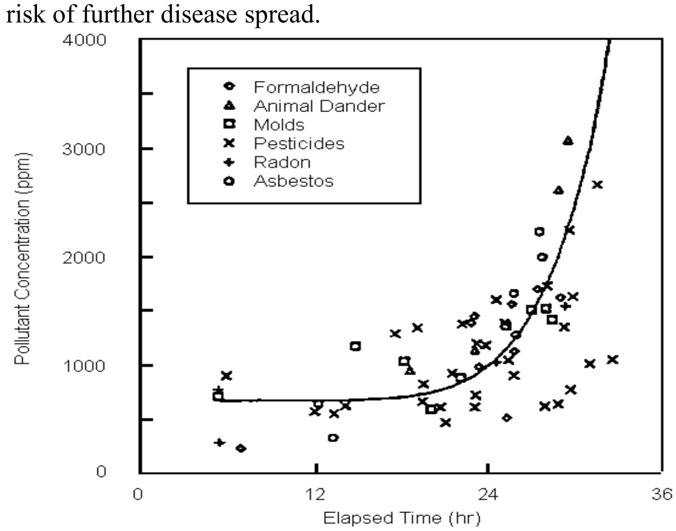

Fig. 4 Indoor air quality monitoring

Automated time series modeling and forecasting technologies, such as regressions, autoregressive integrated moving average (ARIMA) [18], and Holt-Winter exponential smoothing methods [19], are common syndromic surveillance algorithms used to predict the occurrence of future health events. Using a feedback control, [20] applied surveillance methods to three data streams simulated from different types of real-life outbreaks. Ubiquitous healthcare allows sensing of various pollutants that may trigger a condition by utilizing awareness in smart home applications that allow regulation of air flow based on user location [21]. Air pollution data collected by monitoring of areas such as kitchens and living rooms can be used to regulate indoor air quality through prognostics and air flow management of different locations. The relationship between the inhaled amount of pollutants and the probability of accumulation that consequently leads to a disease is mathematically described. For example, the prolonged inhalation of radon gas in the basement may increase the risk of lung cancer while radon decays into a radioactive heavy metal prior to exhalation.

The foundations of epidemiology and early epidemiological models were based on population wide random-mixing. In practice, nonetheless, each individual has a finite set of contacts to whom they can pass infection to; the ensemble of all such contacts forms a mixing network where various sensors can be used to detect the spread movement. Knowledge of the structure of the network allows models to compute the epidemic dynamics at the population scale from the individual-level behavior of infections.

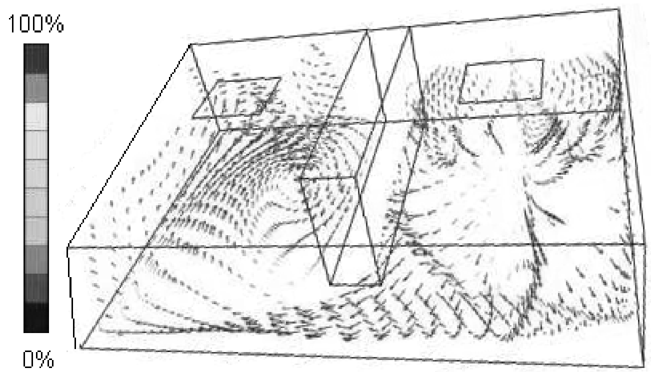

Fig. 5 Air flow simulation between two adjacent rooms

The same model can be applied to both outdoor and indoor environmental monitoring. The later can utilize ubiquitous healthcare health monitoring through regulation of air flow and proactively control the indoor air quality prior to trigger a disease related symptom using prognostics methodology [22]. Monitoring the presence of different pollutions provides necessary information to implement environmentally linked disease syndromic surveillance using a ubiquitous healthcare framework. Fig. 4 shows the elevation of various pollutants that causes a degradation of indoor air quality over time without adequate ventilation. Using a location dependent connectivity scheme similar to that proposed in [23], air flow is regulated according to sensor readings from different locations. Fig. 5 simulates the air flow across two rooms where pollutants can be removed to a healthy level. This ensures the environment will be maintained with an adequately low level of pollutants.

V. CONCLUSION

We have presented a framework for syndromic surveillance of chronic disease using ubiquitous telemedicine solution. While we have focused on asthma in this paper, further research will include other medical conditions and in consultation with medical practitioners.

REFERENCES

[1] B. Fong, A. C. M. Fong and C. K. Li (2011), Telemedicine Technologies: Information Technologies for Medicine, Wiley.
[2] J. Matthing, B. Sanden and B. Edvardsson (2004), New service development: learning from and with customers, International Journal of Service Industry Management, Vol. 15 No: 5, pp.479 – 498
[3] P. Knekt et. Al., Flavonoid (2002) intake and risk of chronic diseases, American Journal of Clinical Nutrition, Vol. 76, No. 3, 560-568.
[4] D. B. Peden (2005), Air pollution in asthma: effect of pollutants on airway inflammation, Immunology and Allergy Clinics of North America, Vol. 255 No. 1, pp. 15-30.
[5] Asthma Fast Facts: A Summary of Important Statistics, available from: http://www.cdc.gov/asthma/pdfs/asthma_fast_facts_statistics.pdf
[6] P Koutrakis, SLK Briggs and BP Leaderer (1992), heaters using kerosene can also produce acid aerosols, Environmental Science and Technology, .Vol. 26 No. 3, pp. 521-527.
[7] Asthma Prevalence, Health Care Use, and Mortality: United States, 2005–2009, available from: http://www.cdc.gov/nchs/data/nhsr/nhsr032.pdf
[8] B. Fong and G. Y. Hong (2011), A Prognostics Framework for Managing Health Degradation and Air Pollution Concentrations (to appear), Journal of Advances in Information Technology. Vol. 2 No. 2.
[9] E. R. Pacht, et. Al. (2009), Effectiveness of Telemedicine in the Outpatient Pulmonary Clinic, Telemedicine Journal, Vol. 4 No. 4, pp. 287-292.
[10] M Contaldo et. Al. (2010), A 2.4-GHz BAW-Based Transceiver for Wireless Body Area Networks, IEEE Transactions on Biomedical Circuits and Systems, Vol. 4 No. 6 Pt. 1, pp. 391-399.
[11] B Fong, A C M Fong and G Y Hong (2005), On the performance of telemedicine system using 17-GHz orthogonally polarized microwave links under the influence of heavy rainfall, IEEE Transactions on Information Technology in Biomedicine, Vol. 9 No. 3, pp. 424-429.
[12] Y. Cui, Q. Wei, H. Park and C. M. Lieber (2001), Nanowire nanosensors for highly sensitive and selective detection of biological and chemical species, Science, Vol. 293 no. 5533 pp. 1289-1292.
[13] G. M. Stamatelos and D. D. Falconer (1996). Millimeter radio access to multimedia services via LMDS", Proc. IEEE Globecom Conf., London U.K., pp. 1603-1607, Nov..
[14] B. Fong, P. B. Rapajic, G. Y. Hong, and A. C. M. Fong (2003). Factors Causing Uncertainties in Outdoor Wearable Wireless Communications, IEEE Pervasive Computing, 2003, Vol. 2, No. 2, pp. 16-19.
[15] K. Lu, Y. Qian and H. H. Chen (2007), Wireless broadband access: WiMAX and beyond, IEEE Commun. Mag., Vol 45 No. 5, pp. 124-130,.
[16] J. Zhang and N. Ansari (2009). On Minimizing the AWG Cost and the Optical Cable Cost in Deploying WDM PONs," IEEE/OSA Journal of Optical Communications and Networking, Vol. 1, No. 5, pp. 352-365.
[17] N. Ansari, G. Cheng and R. N. Krishran (2004). Efficient and reliable link state information dissemination", IEEE Commun. Lett., Vol. 8 No. 5, pp. 317-319.
[18] G D Williamson, and G W Hudson (1999). A monitoring system for detecting aberrations in public health surveillance reports. Statistics in Medicine; Vol. 18 pp. 3283-3298.
[19] H S Burkom, S P Murphy and G Shmueli (2008). Automated time series forecasting for biosurveillance. Stat Med. 2007, Vol. 26 pp. 4202–4218.
[20] W Jiang, and K L Tsui. A theoretical framework and efficiency study of multivariate statistical process. IIE Transactions Vol. 40 No. 7, pp. 650-663.
[21] R Iqbal, A James, J Black and W Poreda (2010), Peripheral Display for Multi-User Location Awareness, Journal of Advances in Information Technology, Vol. 1 No. 3, pp. 116-126.
[22] D. Lau and B. Fong (2011), Special Issue on Prognostics and Health Management, Microelectronics Reliability, Vol. 51 No. 2, pp. 251-254.
[23] K Kumar, A K Vierma and R B Patel (2010), A Location Dependent Connectivity Guarantee Key Management Scheme for Heterogeneous Wireless Sensor Networks, Journal of Advances in Information Technology, Vol. 1 No. 3, pp. 105-115.