

# A Framework for Predicting Droughts in Developing Countries Using Sensor Networks and Mobile Phones

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## ABSTRACT

Drought is the most complex and least understood of all natural disasters and it affects more people than any other hazard. Droughts have become synonymous with the developing countries and in particular the Sub-Saharan Africa where the hazard is chronic. Effects of droughts can be mitigated if accurate and timely drought predications were to be done. Unfortunately, despite the enormous advancements in science, predictions only provide indications of trends. A major weakness of the existing tools is the emphasis on macro/international level information. The tools also tend to ignore the at risk community who happen to be host to very crucial traditional knowledge on droughts. In this paper, we propose an integrated drought predication framework that considers both scientific and traditional knowledge and combines the use of mobile phones with wireless sensor networks to be able to capture and relay micro drought parameters. The framework is an enhancement of ITU's *Ubiquitous Sensor Network (USN) Layers*. In order to accommodate the diverse roles mobile phones play in our framework, Layer 2 (USN Access Networking) is implemented using three sub-layers composed of heterogeneous gateways.

## Categories and Subject Descriptors

C.1.4 [Parallel Architectures]: *Mobile Processors*. C.2.4 [Distributed Systems]: *Distributed Applications*. H.5.2 [User Interfaces]: *User-Centred Design*. J.7 [Computers in Other Systems]: *Early Warning Systems*.

## General Terms

Algorithms, Measurement, Documentation, Reliability, Human Factors, Standardization, Language

## Keywords

Drought Prediction, Developing Countries, Wireless/Ubiquitous Sensor Networks, Middleware, Grid Computing, Mobile Phone Applications, Resilience, Traditional Knowledge

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## 1. INTRODUCTION

Kazem et al [7] defines a Sensor Network, as an infrastructure comprised of sensing, computing, and communication elements that give an administrator the ability to instrument, observe, and react to events and phenomena in a specified environment. By the very nature of sensor networks (mostly remote), the internetworking used is mostly wireless-based and hence, the term Wireless Sensor Network (WSN) is adopted. WSNs based applications have been successfully deployed for weather forecasting/prediction, habitat monitoring, and tsunami warning systems among others. Intensive research in this area has resulted in several initiatives aimed at addressing hardware and software challenges hampering commercial realization of WSN-based solutions. However, most resulting solutions are still out of reach by the developing countries due to their high cost of implementation.

Our underlining hypothesis is the popularity and processing power<sup>1</sup> of smartphones many of which support a wide number of wireless connectivity options<sup>2</sup>. With such features, the mobile phone of today can match desktop computers of less than a decade ago and therefore presents a fertile potential platform for distributed processing. Further, smartphones have increasingly become popular and affordable. For instance, the growth in number of smartphones handsets shipped in 2010 is projected to get to 24% compared to 8% of the overall handsets shipment[6]. Most smartphones users use the phones for a small fraction of a day and mostly for less power demanding applications such making/receiving calls, sending/receiving text/email messages and occasional browsing the Internet. With clear legal and regulatory framework in place, this raw power that lay idle can be harnessed and put into productive use. One common phenomena in the developing countries is that they tend to be predisposed to higher risk from natural disasters related to climate change, have challenged budgets and unreliable power supply. The most common disasters in these countries are droughts[1]. Droughts tend to make the affected communities very susceptible to other calamities such as disease outbreaks, food insecurity, unemployment, inadequate electricity supply, and breakdown of social structures. As Mishra and Singh explain in [10], droughts' impacts are so complex and span beyond the geographical area affected by the drought. On the positive side though, the growth in mobile phones subscription and usage in the developing countries is phenomenal. By 2009 for example, the developing world had a mobile phone

<sup>1</sup> Ranging from tens of MHz to 1000MHz (such as the Lenovo LePhone released in April 2010) and RAM/ROM capacities of over 512 MiB

<sup>2</sup> Multiple GSM Frequencies (850, 900, 1800 and 1900), Bluetooth1, several data links (CSD, HSCSD, GPRS, EDGE) and Wireless local-area network (WLAN)

subscription of 57.9 per 100 people[4]. These phones offer a ray of hope for the developing countries if scientists came up with relevant mobile phone-based applications.

The main contribution of this paper is a framework that harnesses the computing power available on mobile phones in to a computing grid and employing it in predicting droughts in developing countries. In contrast to conventional drought prediction systems that are based on expensive sensing equipment and satellite systems for information dissemination, our framework proposes integration of a cheap solution based on off-the-shelf sensor equipments used in a delay tolerant context to allow intermittent dissemination of the drought information. Our framework borrows from traditional knowledge and is therefore designed with the affected communities in mind.

The paper is structured as follows; **section 2** describes the literature review, **section 3** presents the drought prediction framework and **section 4** is the conclusion and future work.

## 2. RELATED WORK

### 2.1 Drought Prediction

According to Palmer[11], “drought means various things to various people depending on their specific interest. To the farmer drought means a shortage of moisture in the root zone of his crops. To the hydrologist, it suggests below average water levels in the streams, lakes, reservoirs, and the like. To the economist, it means a shortage which affects the established economy”.

Drought prediction can mitigate effects of droughts if decision makers both at the grassroots as well national/regional/international levels are availed with timely and accurate information about spatial and temporal dimensions of drought. This can then be utilized in effective planning and decision-making, all aimed at reducing drought impacts and identifying the appropriate indicators for early warning system(s). Drought prediction should provide information on 1) the duration of the drought; 2) drought severity; 3) the location of the drought in absolute time (initial and termination time points); 4) drought coverage(area); and 5) the magnitude/density of the drought - computed by getting the ratio of severity to duration [9]

Developing countries, especially the Sub-Saharan Africa makes up the core of the global drought problem. Further, agriculture; the first natural casualty of drought, drives the economies of most of the countries in the region[12]. Past responses to droughts in these countries have not yielded satisfactory results because they mostly involved reacting as opposed to pre-emptive approaches. Better results could be attained using people-centred approaches.

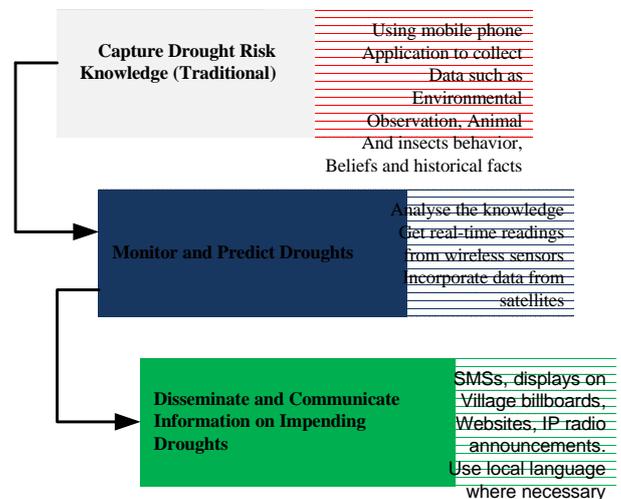
The people, especially the elderly in the affected communities are custodians of crucial information related to droughts. They are known to have predicted droughts/rains in the past with such accuracy by observing their surroundings. These people also have great ideas when it comes to planning and preparing for droughts. Harnessing this knowledge and combining it with modern scientific drought prediction tools such as wireless sensor networks is a sure way of solving this catastrophe threatening to cripple development.

### 2.2 Incorporating Traditional Knowledge into Drought Prediction

In [2], a complete and effective early warning system is described as one that comprises of four components: 1) Risk Knowledge, 2) Monitoring and Warning Service, 3) Dissemination and Communication, and 4) Response

Capability. In order to accommodate the use of mobile phones in capturing of traditional knowledge as well disseminating drought-related information, our drought prediction framework adapts these components as shown in **figure 1**.

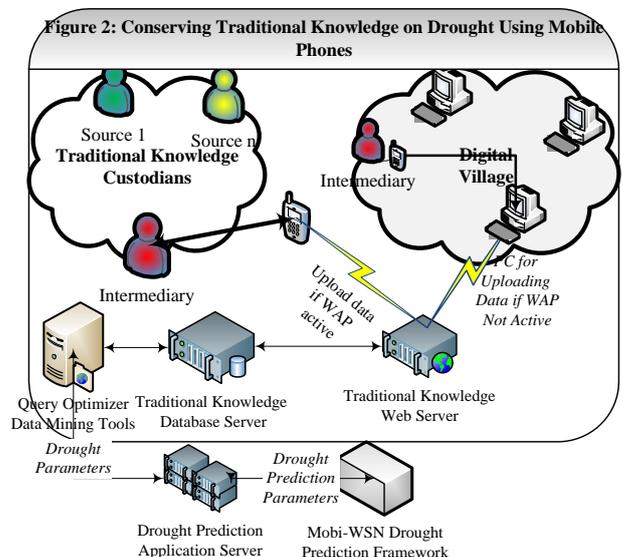
**Figure 1: Components of the Drought Early Warning System**



As shown in **figure 2**, the drought prediction framework harvests the traditional knowledge from the custodians of this knowledge (*Source-1, Source-2, ..., Source-n*) using a mobile phone application. Since most sources of this knowledge may not be literate enough, services of an *intermediary* will be used. Once collected, the data will be sent to the *Traditional Knowledge Database Server* via the *Traditional Knowledge Web Server* either directly from the phone (via WAP module of the application) or by uploading it using computers found in *digital villages*. Once in the database, the data will then be incorporated to the proposed drought prediction framework by first being pre-processed by the *Query Optimizer* and *Data Mining Tools*.

### 2.3 Ubiquitous Sensor Networks

Ubiquitous Sensor Networks (USNs) are described in [5] as networks of intelligent sensor nodes that could be deployed anywhere, anytime, by anyone and anything. Effective and efficient utilization of WSNs and eventually realization of USNs (USNs are not a reality yet) still awaits successful development and implementation of technical standards for



each of the main functional components<sup>3</sup> of WSNs. In[3], 5 layers of USN have been proposed under the heading; *Schematic Layers of a Ubiquitous Sensor Network*.

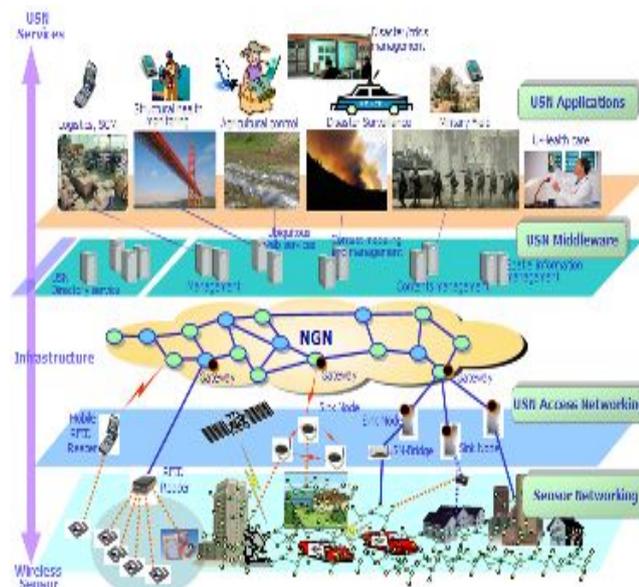


Figure 3: Schematic Layers of a Ubiquitous Sensor Network

**Layer 1: Sensor Networking** – this is made up of sensors that collect and transmit data from their environment;

**Layer 2: USN Access Network** – this act as mediator between the sensors and the control centre;

**Layer 3: Network Infrastructure** – this should be a Next Generation Network meant to carry out networking functions;

**Layer 4: USN Middleware** – software and/hardware that supports the development, maintenance, deployment, and execution of sensing based applications

**Layer 5: USN Applications Platform** – commercial and scientific USN applications

### 3. THE MOBIWSN FRAMEWORK

#### 3.1 Overview

In this paper, an extension to the schema in *figure 3* is proposed. This is necessary in order to accommodate the following salient features of the our drought prediction tool:

- (a) Heavy reliance on grid computing on mobile phone; mobile phones are currently characterized by lower (than a PC) processing power, reliance on insufficient battery power, high mobility, highly heterogeneous (vary in terms of their design and capabilities) and are personalized (mostly for personal private use);
- (b) Drought prediction is mostly based on parameters that cannot be measured with certainty and droughts are often considered to be random events. This will require incorporation of complex computer algorithms;
- (c) Adoption of people-cantered approach; people at the grassroots levels especially farmers will provide the

traditional knowledge on droughts using their mobile phones. Most of them are not literate and information will have to be provided in the local languages as well as in sound format;

- (d) Use of wildlife to collect and transport data. Many developing countries are endowed with wild animals that travel widely; across countries borders at times. Such animals (the less hostile ones like elephants) will be fitted with sensors to aid in data collection/transportation. This and (e) below are aspects of delay-tolerance;
- (e) Use public transport vehicles to collect and transport data. Road transport is still a famous mode of transportation in most developing countries. There are regular fleets of buses transporting people across various towns/cities/rural areas both within and without countries borders. For example, buses transport people from Mombasa (in Kenya) to Dar-al-Salaam (in Tanzania), from Dar-al-Salaam to Kigali (in Rwanda). Fitted with sensors, a lot of climatic data will be collected and transported as the buses transverse borders.

#### 3.2 MobiWSN Framework Layers

Putting the above factors in to consideration, *MobiWSN (Mobile Phone and Wireless Sensor Networks Drought Prediction Framework* in *Figure 4*, is envisaged. In this framework, the mobile phone will play four roles: as gateways, as data mules, as data processors and as application input/output device.

**Layer 1: Sensor Networking Layer**–this is made up of both mobile and fixed sensors that will collect and relay parameters used in predicting droughts; e.g. soil moisture and/or consumptive use, crop yield, leaf index and vegetable growth.

**Layer 2: Lower Gateway Layer**; largely made of android mobile phones that act as gateways to receive data from the wireless sensors. These phones act as data stores, data processors as well as routers. They pass on semi-processed data to the MULE-aware Layer. Given the challenges (discussed earlier) of using mobile phones for computation, a kind of grid will be utilized to increase the system’s robustness.

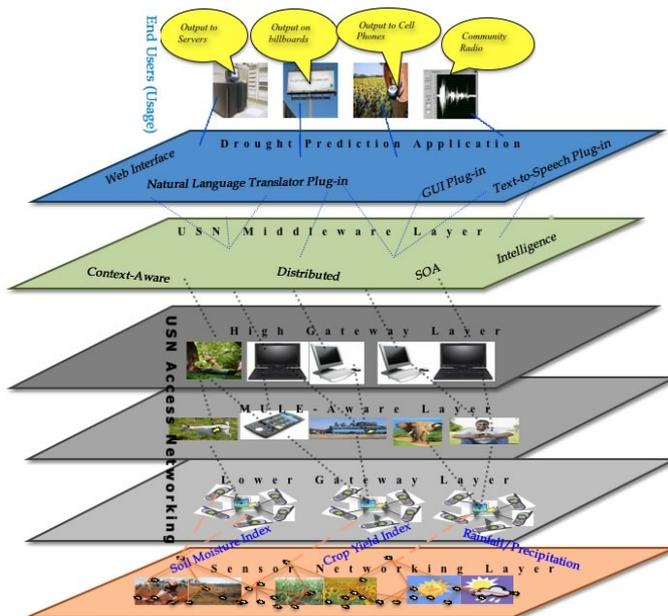
**Layer 3: MULE Aware Layer**; the concept of delay tolerance is again implemented in this layer as demonstrated by the presence of ‘tagged’ wild and domestic animal as well public transport vehicle in the architecture. As these mobile objects (bus, goat and elephant) passes various locations, raw and pre-processed drought data will be exchanged between fixed and the moving network nodes.

**Layer 4 – High Gateway Layer**; this layer is made up of more powerful computing devices such as laptops and workstations that receive data from the MULE Aware Layer and processes it further before passing it on to WSN middleware.

**Layer 5: - USN Middleware** – this is the software layer that acts as an API for developing the drought prediction application. It is context aware (has some intelligence) and uses the Service Oriented Architecture (SOA) to abstract the services offered as mare services that can easily be invoked. The middleware is generic; can be modified to work for any other applications (not necessarily drought predication).

**Layer 6: - USN Drought Prediction Application**: - this is the software that will predict droughts given several parameters. These parameters will be retrieved from the data read by the sensors (and pre-processed in gateway layers), data retrieved from the TK database as well as external parameters from satellites and real-time data passed by selected individuals from the local community using mobile phones.

<sup>3</sup> (1) Sensor Network/sensors; (2) Access Network- intermediary/sink nodes; (3) Network Infrastructure; (4) Middleware; (5) Application Platform



**Figure 4: MobiWSN Drought Prediction Framework**

The drought application's scope is to predict duration and severity of agricultural droughts. This application will be designed in close collaboration with relevant experts such as environmentalists, ecologists, hydrologists, meteorologists, geologist and agronomists. The proposed application is *ubiquitous*[3]. This happens to be a novel (no one known to us has done it before) feature that ensures that the application can be used by anyone, anywhere, anytime and using anything. The 'anything' here is taken care of any mobile (irrespective of the phone's features), IP radio and billboards. The natural language translators and text-to-speech engine support the 'anyone' aspect while mobile phone mobility aids in supporting 'anywhere' and 'anytime' aspects of the ubiquitous characteristic.

#### 4. CONCLUSION AND FUTURE WORK

WSN-based applications have been successfully deployed for; weather forecasting and prediction, health-care monitoring, habitat monitoring, tsunami- warning systems among others. Droughts are among the most expensive disasters in the world whose negative impacts span economic, social and environmental aspects of the affected society. Droughts are common in developing countries; they lead to devastating effects one of them being food insecurity. A WNS-based application can be used to accurately predict droughts and reduce drought impacts. WSN-based applications are recommended for the developing countries because they precipitate desirable features that make them suitable. However, in their current design, WSNs are not feasible in the developing countries due to high cost, perceived irrelevance among other reasons.

In this paper, a viable solution that makes use of readily available mobile phones is presented. The solution combines traditional knowledge, natural (African) language translation and text-to-speech conversion to provide a relevant solution for predicting droughts in the developing countries. Our solution is

designed with full knowledge of some serious challenges of using mobile phones as computing devices as well the inherent challenges that come with WSNs applications' development such as scalability, heterogeneity, data integration, security and quality of service. The *USN Middleware Layer* of our proposed framework addresses these challenges.

This is an on-going research project. The following is some of the planned further work:

- (a) Identification of appropriate sensors for use in drought prediction;
- (b) Testing of MobiGrid[8]; the middleware that will be used in networking mobile phones for the proposed framework. MobiGrid is a prototype that currently runs only on selected Nokia smart phones;
- (c) A survey (using interviews) to determine the structure (if any) of the traditional knowledge on droughts. This will be carried out in selected districts in Kenya. The information will then be used to design and develop a mobile phone application that will be used in collecting traditional knowledge for purposes of drought prediction.
- (d) Evaluation of the existing scientific drought prediction algorithms. This is to determine the necessary extensions/enhancements/inventions to cater for the traditional knowledge parameter(s) in drought prediction.

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