WSN Multi-Tier MDC GRID based Routing Protocol to mitigate Financial Impact

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Abstract
Wireless Sensor Networks (WSN) comprised of several thousands of sensor nodes that can be used as an effective tool for data collection in a variety of fields. With the use of WSN technology, the agri-business aids irrigation controlling, weather monitoring, pest controlling and different levels etc. to avoid financial losses and minimizes risk. As GDP play's an important role in the country economic sustainability so minimization of financial losses to increase the overall GDP of an agro-economic country like Pakistan (generate 70% total export Income by agri-business) is utmost important. Sensor nodes collect aggregated data with minimum energy consumption to save battery life. This paper focused, is to enhance the network performance with minimum energy consumption based on Hybrid Multi-Tier Mobile Data Collector (MDC) based Routing protocol. Hybrid Multi-Tier MDC based routing protocol uses Multi-hop communication and Multi-Tier architecture mechanism. We have conducted simulation based evaluations to compare the proposed protocol with MDC minimum distance. The proposed methodology shows the substantial improvement in minimizing senor node's energy consumption and improves the network lifetime to mitigate financial impact.

Keywords:
Wireless Sensor Networks, Multitier Architecture, Energy efficiency, Mobile Data Collector, Financial Gain, Agri-Business

1. Introduction

Business and industries play an important role in the development of a country since they contribute highly to a country's GDP. GDP is a primary scale that is used to measure a country's economic health, which indicates the country's total buying and selling power in terms of export and import goods produced and the business services that are provided by the country to the global community; and the utilization of such goods and services on a national scale[1]. Profitable business and industries are considered as a good sign of country growth, which aids in trade with foreign countries, generates more revenue, and helps build healthy relationships in the global market. Like business, technology, industrialization, urbanization, inflation rate, literacy rate or education, health, security, and other factors also play an important role in determining a country's economic health and status[2].

Countries that have a large land area covered by farming, cultivation, and other agricultural activities are commonly known as agricultural or agro-economic countries. Pakistan is an example of an agro-economic country. The term "agricultural land" implies that a specified land is Arable that can be used for growing permanent crops or permanent pastures, excluding the land that has been shifted or abandoned [3]. The agricultural sector will always be the backbone of the country and this cannot be oversighted in the race towards development in the future[4]. Pakistan is a land that is blessed with plenty of natural resources including Oil, Gas, Mountains, Lakes, Arable and Fertile Land, Deserts, Rivers, etc.[4], [5]. The total land size of Pakistan is about 796,095 km², of which about 47.06% (in 2013)[6] and 47% (in 2014) was reported to be Arable land. According to a document by the ministry of finance, the contribution of agriculture to the economic growth development was reported to be 19-22% during the years 2009 to 2012[6]–[11], and 24% in 2015[12]–[14]. It is the second largest economic contributor for the country[15]. The population of Pakistan is around 20 million (207,774,520), according to the census 2017 with an average growth rate of 2.4% since 1998[16]. A large ratio of the population of Pakistan resides in rural areas that covered nearly 68-70%[11], [17] in 1998[9], [16] and reduced to 64%[9] according to the census report of 2017[16] which is still a very high proportion of the country population. This population also conserves the largest employment ratio which is about 68-72%[9], [10], [13] of which 43.2%-45% belong to agricultural sector[6], [7], [9]–[11].

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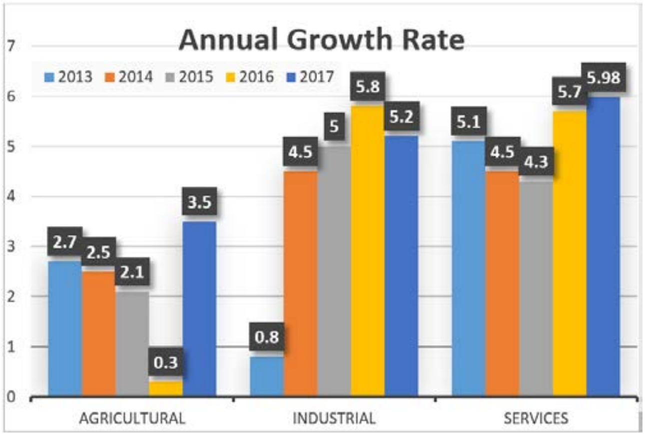


Figure 1. Sector wise contribution to GDP since 2013

In Pakistan, agricultural sector directly impacts export revenue generation since it covers about 70% of total export income of Pakistan[13], and indirectly impacts many other sources that affect the GDP[2], such as food supply to consumers, raw materials and fibers to local and national industries, source of export revenue and global trading, provides industrial goods, and supports employment to relegate poverty[8]. Fig 1 shows the contribution of agricultural, industrial, and business services towards the GDP during last five years. Figure 2 shows the annual impact of single agricultural sector in country's GDP.

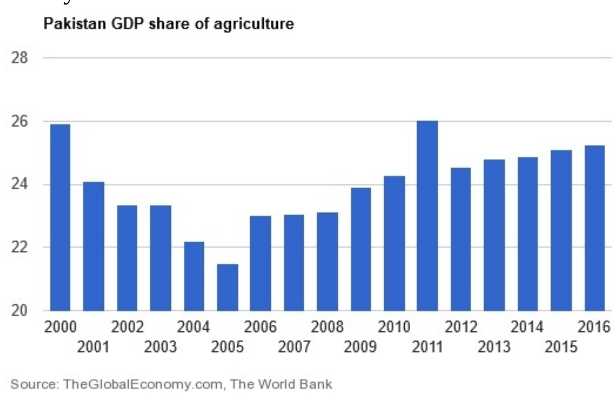


Figure 2. Annual Agricultural Share in GDP since 2000-16

The growing concern of managing supply demand of food comply with the rapidly growing world population which drives more responsibilities and challenges to agricultural sector. The need of producing and availability of the right amount of food time in due time requires better planning, care, attention, and information about the climate changes and pest protection.

2. Massive expenditure associated with Agri-Business

The agricultural sector is one of the oldest professions in human history which is accountable for sustaining and enriching life. These tasks require genteel management, administration, and understanding of farming methodologies for cultivating plants, crops, trees, and raising farm animals which assists in farm fields and allows the production of foods[18]. But, the agricultural sector is jeopardized with uncertainties of global environmental changes like weather, rainfall, temperature, transforming season slap etc. which have a direct and strong impact on farming making it a problematic and risky choice[2]. Besides these natural calamities, the traditional approach of agriculture and farming is insufficient to fulfill the production requirement of the population. This approach also encounters threats to production yields in the presence of outdated machineries[19], aged infrastructure, and inadequate irrigation system[20] including five main risks that are environmental, human resource , legal, production, financial, and marketing. Among these five, except for the issue of finance, the other four are indirectly associated and interdependent on the availability of financial resource[2].

On the contrary to natural disaster and risks, the other major problems agriculture faces are due to incomplete and inappropriate knowledge of conditions for fertilizing seeds. Sometimes, farmers mistakenly predict the wrong weather and plant fields or take cultivation action that damage the agricultural fields which ultimately results into lesser production yield. Moreover, in large farms and fields, it is hard for human resource to periodically monitor the entire area in due time for identifying what action to take next such as to protect the field from insects, spray at the right time, maintaining water level of crops using the right irrigation method, etc.[2], [21], [22]. It is also troubled by structural, machinery, and irrigation water problems[19]. Following Table 1[4], [10] exhibits the annual agricultural growth rate for the last 5 years. Statistics clearly show that the disturbance in recent years is not only damaging the performance of the agricultural sector, but also badly costing the farmers due to poor planning, observation skills, traditional techniques, and outdated equipment. The heavy unbearable losses sometimes result into the farmers selling out their lands to others, or in worse cases, even committing suicide.

Table 1 Annual agricultural share in GDP and Depletion rate

Year	Agricultural				Share in GDP	Rate w.r.t Prev. Yr
	Major crops	Minor crops	Livestock	Forestry		
2010-11	5.3	2.9	11.9	0.5	21.7	-0.3
2011-12	5.5	2.6	11.9	0.5	21.6	-0.1
2012-13	5.4	2.6	11.9	0.4	21.5	-0.1
2013-14	5.4	2.5	11.8	0.4	21	-0.5
2014-15	5.3	2.3	11.8	0.4	20.9	-0.1
MEAN	7.29	3.25	11.17	0.43	23.02	-0.182

In present circumstances, standing obstacles in farming and agricultural industries require promising new supporting techniques and technological advancement[23][24] which not only assist in catering to the intended environmental deviations, irrigation controlling, real time crops, water level and farm animals monitoring, but also provide pest prevalent information and a pest protection system to assure definite yield production for avoiding loss and minimize the uncertainties of associated risks[25].

3. ICT Integration in Agri-Business

Since the last decade, after the dawn of ICT and MEMS integration, WSN has emerged as a promising technology. In just a few years, WSN has rapidly attained massive global attraction which gives a new perspective to deal with things contrary to the traditional and old-fashioned approach of performing tasks. This has not only enlightened and introduced a modern innovative way to answer the standing questions, but its usability, portability, compatibility, programmability, configurability, controllability, flexibility, scalability, modularity, robustness, high performance, ease of deployment, and the most importantly, its affordability makes it a prominent, cost-effectiveness solution for the present era[23], [26]–[32].

The advent of WSN into farming and agricultural industries, also brings significant revolutions in “Precision Agriculture” (PA). PA is a set of technologies and methodologies[30], whose core objective is the competent use of modern technology and management stratagem to improve land farming and agricultural production yield, quality, and quantity in several perspectives[33], [34]. The technological progression plays vital roles in enriching the output production[27] which takes historical knowledge, environmental variables such as humidity, moisture temperature, weather condition etc. into consideration to apply a predictive approach and decisions are made in real time based on technological information, labor interaction, seed quality, water availability and level and other factors as inputs[24] that can be applied in both open farm fields (irrespective of size) and indoor cultivation environments[21], [33].

4. Global trends towards WSN

Whenever a new technology is introduced or the integration of two (fields/technology) emerge into a new improving one, it changes the paradigm of thinking and usability. The most important concerns and considerable questions that come to mind when adopting and accepting a new technology are: Does technology really help or is it just theoretical sweet talks? Does the world really prefer this technology integration? Is this technology worthy enough to be used in agricultural and farming industries? Several other similar concerns are raised as well.

Like many countries such as Pakistan, Egypt is also an agricultural country. In the last few decades, it has had a crisis in its core dominating sector which resulted in significant production loss, low quality of output, and downgraded export. The continuous forfeiture and long-term crisis turned the agricultural opportunity into a threat for Egyptian farmers and the agriculture industry. People looked ahead to turn away from agriculture to other business opportunities to earn better this brought a further increase to food requirements. Thus, agriculture in Egypt is now more concerned with improvement and technological enhancements that would assist in the production of high-quality crops. Currently, many experiments and studies have been applied and are in practice, such as S. El-Kader et.al [35] who studied and designed a WSN based solution for potato crops to enhance the production and quality for export and high revenue generation, as Egypt is one of the largest potato producers and exporter in the Africa region. In this experimental study work, WSN is deployed uniformly over the field using APTEEN and LEACH as routing protocols. The solution implemented as a decision-making tool and it takes benefit of WSN application for the early classification of old land health, harmfulness and disease factor for plantation suitability, and suggests reclamation of land. The study found that the cost of WSN solution, based on annual benefits from production and export is acceptable, and is estimated to be covered in around one year which diminishes the export and monetary loss for the country i.e. financial benefits of WSN solution. While the nodes lifetime is determined to be about 6.5 months which is more than enough for harvesting one entire potato field in Egypt.

M. Srbinovska et al. [36] conducted experimental deployment of WSN application Pepper plantation in a greenhouse situated at 100km distance from Skopje, the Republic of Macedonia. Pepper vegetable is among the most sensitive crops in the world, which requires high control levels and an extremely favorable environment for quality production and successful harvesting. The most critical factors in pepper crops are temperature, soil pH levels, humidity in the air, and adequate irrigation. Thus, it requires continuous monitoring and testing of soil, air, temperature that keep varying from early morning to bright sunny hours, and breezing sunset to cold night. Negligence of any single factor might result in undesirable production quantity or impairment of the entire field. Several experiments were performed with varying network parameters 1) two nodes transmit data every minute for 3 days, 2) five nodes transmit data every 30 minutes for one week, to determine the accuracy of performance and decision-making to identify which action should be taken. The WSN application system instantaneously takes the appropriate action through its smart decision-making ability and manages the devices operation to power on or off equipment such as fan.

M. Dong et al [37] proposed the application centric MAMS data aggregation technique to prolong the network life and maximize the battery utilization of node in WSN , called TinyBee for agricultural. The presented technique is exemplified as the bee hive; where mobile agent (MAs) pretend as bees that are sent off by the mobile Sink (MS). In this scheme, as by name MA and MS are non-fix and other sensing nodes may be stationary or moveable. MS is the destination end of data that is traveling along a specified path in the field. Whereas, MAs traversing all the surrounding nodes and responsible to gather the data from the sense field to deliver to MS. Besides this, as MS also moving along a predefined route, MAs also responsible to locate the MS location by using a geographic routing technique that is shared with MAs only and using appropriate path MAs reach MS to sink the collected data. Thus, sensing nodes does not need to know about MA or MS location, not even concern with neighboring node(s).

Muhammad et al. presented the three tier architecture for MDC based routing in [38], in this scheme MDC is participating as middle layer facilitator in topology to save corresponding child nodes' energy. In this architecture, at root or top level is Base Station (BS) then the sensor nodes is randomly deployed and whole area is divided into the GRID / Cluster, after that sensor nodes select Cluster Heads (CHs). [38] introduced the MDC, which is moving in predefined trajectory and responsible for collecting data from CHs that may be near or far apart from BS and deliver data to sink node. Irrespective of the distance from sink node, cluster nodes are meant to transmit data to their heads, and then the heads are responsible to share them with MDC to finally deliver it to the end-point. This architecture minimized the node activity and information overload and restricting cluster nodes in intra-domain communication while inter-domain routing only done between CH-MDC-BS.

5. Hybrid Multi-Tier MDC based Architecture

Motivating from the presented work of Muhammad et al. in [38], in this research work, proposed the new Hybrid Multi-Tier MDC based architecture which distribute the transmission overload of MDC and prevent unnecessary multihop communication to maximize the node(s)' life, enhance network performance, reducing end-to-end delay time and maximize the battery utilization which is ultimately result in prolong the network life to mitigate financial impact. The following Fig. 3 showed the proposed hybrid Multi-tier MDC based architecture. The Base station or sink node is the root destination end-point of concern data from the sensor node(s). MDC is middleware facilitator between CHs of clusters and BS, and CHs is a single point of concern of each cluster that is responsible for its member nodes. Besides the nodes role in architecture, the figure also state that CH can directly communicate with BS, if and only if the transmitting or communicating node is closer to the BS. If the CH is not nearer to the BS or MDC it will deliver data to other nearer CH by calculating the distance factor. This implies that intra-cluster domain communication of node(s) restricted to their relative cluster and inter-domain communication is advanced by allowing shortest and multipath conditional routing technique within CHs, MDCs and BS.

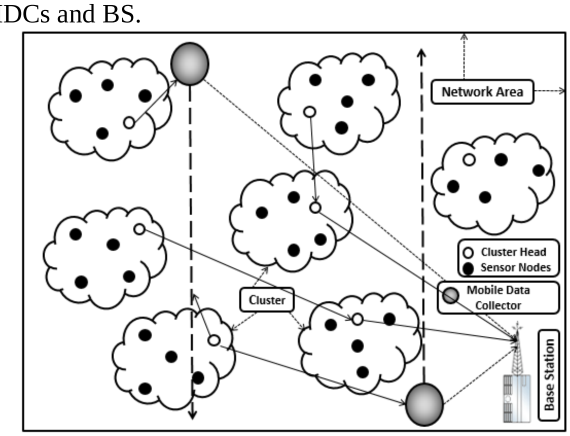


Fig. 3. Hybrid Multi-Tier MDC based Architecture

6. Results and Discussion

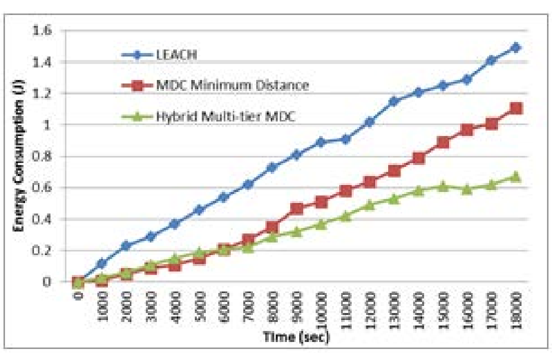
The proposed solution is simulated under OPNET network modular environment to determine the worth and compare the results with previously presented results using the same parameters of [38] listed in Table 2.

Table 2. Simulation Properties

Parameters	**Values**
Number of sensor	40
Agriculture Land	1 km^2
Transmission electronics ($E_{TX-elec}$)	50 nj/bit
Receiver electronics ($E_{RX-elec}$)	
Transmit amplifier (εamp)	100 pj/bit/m^2
Node energy	2 joules
Number of MDCs	2
MDC beacon message rate	5 s
MDC velocity	0.054 m/s
MDC energy	30 joules
Packet size	160 bits/packet

In this experimental work, a number of 40 nodes used that randomly deployed in a 1 km2 area. Where, each sensor node (N) has the limited energy of 2 joules and MDC that is mobile in nature has 30 joules, which assure that MDC should not die before the sensor node. MDC displacement velocity is set as 0.054 m/s and the size of each data packet is considered as 160 bits/packet.

Due to mobility of nodes, it is possible that the number of sensor nodes within the GRID / Cluster varies and CH in each periodic round can also be changed. The node which is previously selected as CH cannot be elected in consecutive round, but the previously chosen CH might be pickup as CH after second round based on the nodes' parameters statistics among the clustered nodes. Considering the node(s) behavior and election procedure of CH, it is possible that CH either not consumes much energy in some or consumes more energy. Thus, it is possible that rapidly selected CH (node) of a cluster may die early will not be part of a network and new CH will be elected from a cluster to keep a network alive. Several performance metrics of node such as Energy consumption of sensor nodes and Network lifetime, are measured by conducting the multiple simulation and their results presented in fig. below.



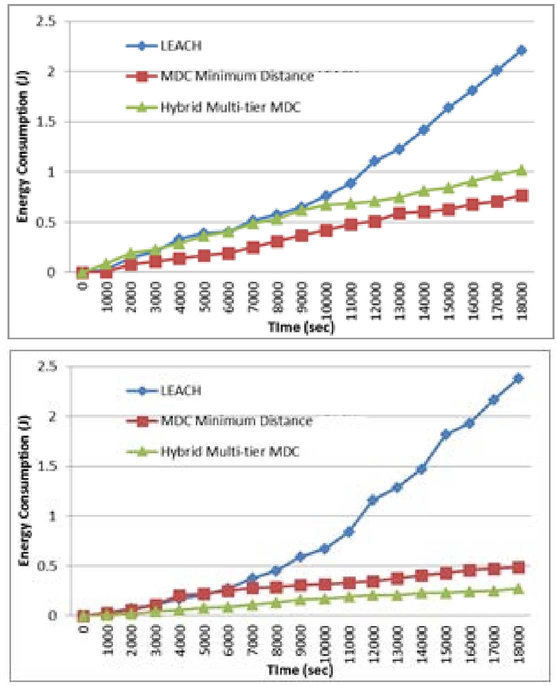


Fig. 4. Energy depletion comparison of random nodes

The energy consumption of individual nodes that arbitrarily selected from the environment as shown in fig. 4, from left to right, it shows the Node 5, 19 and 36's energy consumption along with the utilization in LEACH and MDC Minimum Distance. It is clearly observed that the Hybrid Multi-Tier MDC based protocol turns the best among three, which used minimal energy during simulation and increase nodes' life. As LEACH consumed 100 percent energy in simulation, and MDC Minimum Distance used more than 50 percent of energy, while the proposed solution comparatively consumed much less energy.

Fig. 5 represents a comparative chart of a number live participating nodes of a network after complete simulation. In below chart, Hybrid Multi-Tier MDC based protocol shows the exceptional performance as compare with LEACH and MDC-Minimum Distance. The Number of nodes under LEACH protocol, frequently dying after one hour and only few are left after 5 hours. In MDC-Minimum Distance, network start losing the nodes after 2 hours of working and around 25 nodes are left that facilitating the intended service. On the contrary, Hybrid Multi-Tier MDC based protocol lost the total 5 nodes only. It is possible that the lost nodes are the CHs which are rapidly elected as cluster head or moving extensively in the network region.

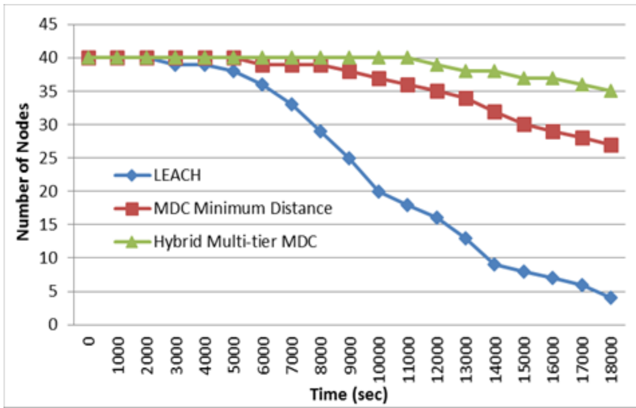


Fig. 5. Number of Live Nodes Comparison

The above simulated results are summarized in the Table 3 to give quick insight of simulated result.

Table 3. Brief Simulated Results

Attributes	Hybrid Multi-Tier MDC based Protocol	MDC Minimum Distance	Single-hop LEACH
Node energy depletion	Min	Med	High
Node Life	High	Med	Min
Network lifetime	High	Med	Min

6.1 Cost Benefits Analysis

Traditional Agri-business techniques are far different than new modern agricultural approaches which differ in their phenomenon of cost association and benefits. Table 4 summarized different parameters with traditional Agri-process as compared to WSN-Agri.

Table 4 Parameters Comparison

Parameters	Traditional Agri-Process	WSN-Agri
Workforce	Directly proportional to the farming land size. The larger the land, the more the labor required to manage and prepare it for crops in due time	No additional work force required. Regardless of farming land size. Work can be done in presence of minimal workforce with minimal human interaction
Irrigation	Water supply and water level observed and maintained manually. **Labor Required w.r.t size and time**	Sensors nodes continuously monitor fields with respect to the crops to maintain and supply water.
Fuel cost	Vehicles required to survey crop field and in other works. **High**	No vehicles required to monitor and survey field. Thus, save fuel cost. **Low**
Weather	Based on personal observation and news broadcast (paper, TV, Radio) or sometimes even unaware of weather. **Error probability High**	Based on data collected by sensor nodes and real-time weather condition. **Error probability very Low**
Monitoring	Manually, on field monitoring Error probability High Time required is High Human life risk is High	Fully/Semi-Autonomous Instantaneous monitoring Error probability Low Time require is Less Human life risk is low
Mitigation approach	Reactive	Proactive
Life risk	Risk of wild animal's attacks on farmers is High	Instantaneous information keep aware of field statWSNus. Thus, minimal life risk.
Time cost	Varies by land size	Minimal irrespective of size
Financial Cost	High	Medium

Unattended WSN managerial solution significantly resultant in controlling the financial constraints and aids in essential sensitive Agri-process such as environmental, irrigation, pest and wild animal monitoring, which safe human efforts, cost, time and life in proactive manner.

7. Conclusion

This research work has addressed the implementation of multi-hop and multi-tier cluster based routing protocols from sensor node to the base station via Cluster Head and Mobile Data Collector. Through a wide range of simulation scenarios, the results showed that the proposed Hybrid Multi-Tier MDC based routing protocol decreases the energy consumption of the individual sensor node and enhanced the network lifetime, significantly compared with the previously best known routing protocols. In future, the authors will improve the Hybrid Multi-tier MDC based routing protocol to use a multi-channel implementation instead of a single channel at the base station to directly assigned the channel for the CH's and MDCs and hence increase the life time of the network to mitigate financial impact.

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