Optimal Wireless Technology Selection Approach for Sustainable Indian Smart Grid

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Abstract

The smart grid is playing a game-changing role in achieving clean and green energy, infrastructure, and cities, which are all part of the sustainable development goals. The significance of communication infrastructure in the reliable design and operation of the smart grid is well recognized, notably for renewable integration, facilitating distributed energy resources and storage, demand response, and energy efficiency. Since choosing the optimal communication technology is a strategic decision, the problem needs careful investigation, taking into account realistic data traffic estimates to fulfill the communication needs of the applications envisaged. Even though a vast array of technologies with diverse capabilities is available to meet such communication needs, choosing the optimal wireless technology for a smart grid project remains a difficult challenge. In this context, to achieve and maximize the benefits of the smart grid and its applications, a systematic and efficient approach is necessary. This study proposes a data-driven decision-making approach for evaluating the capabilities of viable wireless technology

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options and selecting the most suitable option for the smart grid project at the design phase. The suggested approach and the decision-support tool were developed using a cost-function-based optimization technique. A case study of Siliguri city Indian smart grid pilot is discussed to validate the potential and aptness of the presented approach and suggest better technology alternatives as replacements. Being field data-driven, the presented optimization approach is simple, customizable, strategic, and re-usable with practical efficacy to assist decision-making.

Keywords: Automation, communication, data acquisition and analysis, data-driven decision-making, evaluation, instrumentation and control, instrumentation telemetry system, optimal selection, optimization, smart grid, sustainable energy.

Nomenclatures

i = Index for smart grid applications

j = Index for wireless technologies

R_{Ni} = Data rate requirement to cater ith application

M = Highest data rate amongst all the applications planned

$\mathrm{P}_{\mathrm{bpsNETj}}$ = Proportional data rate receivable for a particular fixed bandwidth, if j^{th} technology is used

$\mathrm{NWLAT}_{\mathrm{i}}$ = Highest latency permissible to cater ith application

$\mathrm{MAX}_{\mathrm{NLAT}}$ = Highest latency value amongst all the possible communication technologies under study

$\mathrm{TotLat}_{\mathrm{ij}}$ = Overall value of delay = TP + $\mathrm{RTT}_{\mathrm{i}}$, RTT_{i} = Round Trip Time in seconds while using ith application, TP = Processing Time in seconds

$\mathrm{W}_{\mathrm{DRij}}$ = Weighted data rate, if ith application is used with jth technology = $\mathrm{R}_{\mathrm{Ni}}/\mathrm{M}$

$\mathrm{N}_{\mathrm{DRij}}$ = Normalized data rate, if ith application is used with jth technology = $\mathrm{R}_{\mathrm{Ni}}/\mathrm{P}_{\mathrm{bpsNETj}}$

$\mathrm{W}_{\mathrm{delayij}}$ = Weighted latency, if ith application is used with j^{th} technology = $[1-(\mathrm{NWLAT}_{\mathrm{i}}/\mathrm{MAX}_{\mathrm{NLAT}})]$

$\mathrm{N}_{\mathrm{delayij}}$ = Normalized Latency, if ith application is used with jth technology = $[1-(\mathrm{TotLat}_{\mathrm{ij}}/\ \mathrm{NWLAT}_{\mathrm{i}})]$

$\mathrm{CF}_{\mathrm{ij}}$ = Cost Function to optimize the balance of capabilities of j^{th} wireless technology against the communication requirements of i^{th} smart grid application

1 Introduction

The smart grid is demonstrating undoubtedly vital potential as bidirectional participatory energy and information transmission platform to achieve various Sustainable Development Goals (SDGs) [1]. Basic applications such as Supervisory Control And Data Acquisition (SCADA), Meter Data Management System (MDMS), and Automated Metering Infrastructure (AMI) form the foundation of the smart grid. Other smart grid applications, such as Distributed Energy Resources and Storage (DERS), Peak Load Management (PLM), Demand Response (DR), and so on, contribute to affordable and clean energy (SDG7), Distributed Generation and Management (DGM), and Power Quality Management (PQM) support Innovation and Infrastructure (SDG9), Wide Area Situational Awareness (WASA), Plug-in Hybrid Electric Vehicles (PHEV), Home Energy Management (HEM) enable Sustainable cities and communities (SDG11). In addition, all the smart grid applications actively facilitate the attainment of other sustainable development goals, such as responsible consumption and production (SDG12) and climate action (SDG13) [1].

The role of electricity as an essential consumable is becoming irrefutable, not only for economic growth and lifestyle enhancement, but also to sustain daily living. However, the worldwide deficit of power has been growing steadily due to growing population, longer life expectancy, difficult to anticipate rapid changes in weather conditions, etc. The conventional electricity grids are now obsolete, antiquated and susceptible to natural disasters as well as to cyber assaults. As a consequence, the world need ICT-enabled, intelligent, swiftly responding, resilient grids often known as ‘Smart Grids’ for efficient generation, transmission and distribution of power, integration of renewables as well as offer plethora of novel applications [2].

India – the largest democracy in the world, has always strived to overcome the deficiency of electricity for achieving fiscal development and enhancement of quality of life of citizens. As an effort towards this objective, rural electrification is a massively implemented program in India and the rural consumers are immensely benefitting by active participation in the utilization of renewable energy resources [3]. Similarly, for greenhouse gas reduction with low operating expenditure, smart microgrids with suitable energy storage capabilities are also gaining popularity [4]. Mega urban revamping and infrastructure development projects are accelerated under the Smart Cities Mission with an aim to create 100 smart cities. To ensure seamless availability of electricity, under the flagship ‘National Smart Grid Mission (NSGM)’ scheme, numerous smart grid initiatives have been funded by the government to transform the present unidirectional transmitting electricity grids into modern, bidirectional, and intelligent smart grids by leveraging ICT.

By integrating renewable energy resources, the smart grid facilitates citizens' metamorphosis from consumers to Prosumers (Producers+consumers) and acts as the smart city's energy backbone [5, 6]. The variable unit price of power consumed during peak and off-peak hours is enabled by such a smart platform of the electrical grid, which stimulates affordability-based rescheduling of electricity consumption, resulting in peak-shaving via changes in energy consumption patterns [6]. In this, the communication system plays a key role by furnishing real-time pricing-based choices opted by the Prosumers to the utility, based on the same subsequently the utility control systems implement automatic control actions on the field instruments. In a nutshell, fast, accurate, and efficient communication technology is mandatory to serve as a central nervous system catering to live data for the effective realization of the smart grid.

Owing to their inherent drawbacks, wired communication technologies are presently out of favor. For example, Power Line Carrier Communication (PLCC), fiber optic, and wired Ethernet are relatively more costly, complicated to install and maintain, require skilled manpower. Additionally, PLCC lacks standardization and requires advanced noise filtering and correction mechanisms. During conditions such as cable breakages, power switch off, etc. result in non-reliable functioning. Therefore, wired communication technologies are relatively less popular, especially in remote rural areas. In contrast, wireless communication technologies offer attractive alternatives due to their simplicity, cost-effectiveness, user-friendliness, and scalability. Hence, the investigation in this work is kept limited to wireless communication technologies only.

For an upcoming smart grid project, an optimal choice of the best-fit wireless communication technology is a complex design problem due to multiple factors impacting it. Each smart grid installation is distinctive, on account of consumers' quantity and their classification, opted applications for installation, and limited viable alternatives of wireless communication technologies. Therefore, the choice of best-fit technology for a smart grid project is a complex challenge. A systematic approach is required for smart grid communication technologies to address and resolve such challenges at the design level itself. Such a comprehensive approach should consist of provisions to provide an efficient choice of wireless technology for a smart grid project at the design stage.

The design level challenges involved with the smart grid communication system are:

(i) How to evaluate communication requirements for an intended smart grid project?
(ii) Which factors influence the communication requirements of the smart grid project?
(iii) How to evaluate and ascertain which wireless communication technology options can satisfy the communication requirements evaluated in (i) above?
(iv) Which wireless communication technology shall be the best-fit choice out of the suitable options scrutinized in (iii) above?

Therefore, the most frequently encountered challenge faced by the smart grid design engineers has been "*which wireless communication technology should be selected for intended smart grid installation for given geographic location?"*

In this paper, we consider choosing best-fit wireless technology from feasible alternatives as to the research problem and propose an optimization approach with a decision-support tool to help design engineers in optimal decision-making as a solution. We also present the results of testing the proposed approach by implementing it upon real-life example study of Siliguri city smart grid pilot of India graphically depicted in Figure 1.

The following are the important contributions of this work in light of the above discussion:

(i) to emphasize the significance of choosing the most suitable communication technology for a smart grid project
(ii) different smart grid applications and their communication needs
(iii) different wireless technology options, their capabilities, and feasibilities
(iv) survey of different approaches to select best-fit communication technology
(v) proposed optimization approach–a mathematical framework for selection of best-fit technology suitable to the geographical location of the smart grid project
(vi) case study of Siliguri city smart grid pilot of India
(vii) useful recommendations for design and field engineers

The remainder of the paper interprets the following sections: the review of relevant literature is discussed in Section 2. Section 3 puts forth an optimal approach along with a decision-support tool, for examining capabilities of available alternatives and selecting the optimal wireless technology. Section 4

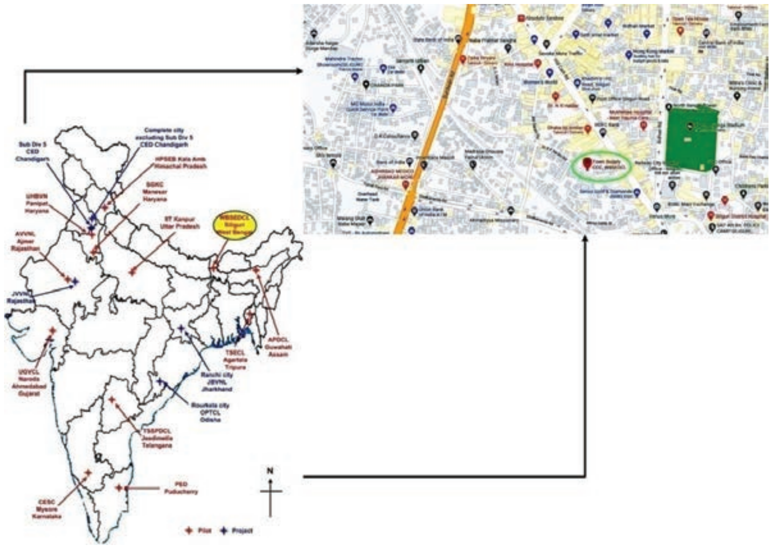

Figure 1 Geographical map of the Indian smart grid pilots and projects, and the Siliguri city Indian smart grid pilot [7].

illustrates the case study of Siliguri city Indian smart grid pilot to validate the proposed approach. Results along with the conclusions are discussed in Sections 5 and 6 respectively, with acknowledgments, a list of abbreviations, and cited references at the end.

2 Literature Review

This section provides a review of literature on the communication system design of smart grid, with a focus on selecting the most suitable wireless technology. The primary goal of this review is to present background and theoretical information to propose a data-driven mathematical approach for selecting an optimal, efficient, and most suitable wireless technology for smart grid rollout during the design phase. In addition, it also contributes by discussing the importance of relevant works. The contributions and novelties of the work presented are also highlighted.

Smart grid (Power) is the first core sub-system under ‘Physical Infrastructure’, which is the first pillar out of four main pillars of smart city evolution. To realize the smart city, ‘Instrumentation and Control’ acts as the first and main enabler and its communication system plays the main game-changer role. From the perspective of an instrumentation engineer, a profound analogy exists between Instrumentation Telemetry System (ITS) and Smart

Grid Communication System (SGCS) [8–10], therefore, while designing a communication system, the smart grid's applications and relevant parameters need careful investigation. Smart grid is considered as a Cyber Physical System (CPS) and overall reliability of the smart grid is therefore dependent upon the reliability of its communication system [11]. Therefore, to serve as a central nervous system catering to real-time data, the selection of a fast, accurate, and efficient wireless technology towards the effective realization of smart grid applications is a complex challenge for design engineers.

At the preliminary level, the detailed surveys of major applications deployed, their enabling technologies, communication system, network architectures, IoTs, etc. are required to study along with relevant wireless technologies and standards [8, 12–14]. Three main networks—(a) Home Area Network (HAN) for field data acquisition at the residential level, (b) Neighborhood Area Network (NAN) at premises level for data aggregation and transportation, and (c) Wide Area Network (WAN) at backbone level to bridge consumer and utility, constitute the smart grid's communication architecture. Each of these networks is deployed to serve specific functionalities, relevant applications using it and therefore, has its specific communication requirements [15, 16]. Our work presented in this article is focused on the design of NAN; however, it can be easily customized to apply the other two networks as well.

Specifications of wireless communication technologies, standards, and protocols [17] as well as important factors affecting communication such as data traffic characteristics, classification, criticality-based priority [18], data rate, latency, coverage, reliability [19] are also surveyed. To qualify as the optimal communication technology, the main criteria is the capability to cater communication needs of smart grid applications and the main factors are data rate, latency, and reliability [19, 20] considered as Key Performance Indicators (KPIs) [21]. The need for clear guidelines or frameworks and unavailability of standards are the bottlenecks and a simple, customizable and practically useful approach towards optimized usage of communication technology is yet an unfulfilled challenge [22, 23].

To develop the proposed optimization approach, an algorithm for the selection of communication networks based on available bandwidth in heterogeneous environments is studied [21]. The algorithm is tested for cellular 2G and 3G networks in temporal and spatial domains. The scope of the work is limited to heterogeneous environments and implementation to cellular 2G and 3G networks.

Using the cost function optimization approach, the smart grid communication technology selection approach is presented, intended to investigate wireless communication technologies [24]. This valuable contribution is focused on the design of Heterogeneous Networks (HetNets) and effective spectrum utilization has been studied for the development of this work. The scope of this work has been limited to three wireless communication technologies and a few smart grid applications applicable to HetNets. This work suggests scheduling of data traffic based on priority or switching networks based on availability, while our work is focused on the selection of technology.

Our proposed optimization approach includes eleven wireless communication technologies and nineteen smart grid applications. As an outcome, our decision-support tool [25] generates the top three best-fit alternatives of wireless communication technologies. Furthermore, our approach is tested by implementing it on the real-life case studies of Indian smart grid pilots. Although seeks inspiration from [24], our work is significantly different in terms of a larger and more diverse sample size of data and varieties of installations studied. Our work presented in this paper is more comprehensive; practical application-oriented and has more potential to be useful to design engineers.

In the development of our work presented in this paper, we utilized a similar cost function-based optimization technique [24]. However, instead of limiting the work to only mathematical algorithmic analytics or simulation results, we have tested our proposed approach presented in this paper by implementing it on the real-life data of the Indian smart grid pilot, which has been a distinctive feature of our work.

To address the challenge, an optimization approach based on Cost Function (CF) based optimization technique was proposed as a solution in this work for making an efficient and robust selection of best-fit wireless communication technology options. Although there are other Multi Criteria Decision Analysis (MCDA) [26] based approaches that are also available and quite efficient, our proposed approach looks attractive on account of being relatively simple, flexible, and customizable. Avoidance of misclassification and the ability to work with lesser complexity and computational resources are additional attributes of our approach.

3 Methodology

Due to various factors impacting, the optimal choice of the most suitable communication technology for smart grid rollout is a complicated design challenge. Every rollout of a smart grid is distinctive, as it consists of different types and quantities of customers, opted applications for installation, and limited viable alternatives of wireless technologies. This section includes a discussion related to the solution methodology of the identified research problem. A mathematical representation of the proposed optimization approach is presented along with an algorithm for the decision-support tool.

3.1 Optimization Approach

First of all, the quantum and characteristics of the possible data traffic are estimated by calculating the communication requirements for the applications implemented or selected for implementation under smart grid rollout. Subsequently, the capabilities of all feasible wireless technology alternatives are examined, to verify and confirm whether and to what extent each technology option can satisfy the communication requirements estimated earlier. Finally, the best-fit wireless technology options are generated and suggested employing the proposed optimization approach [25] along with Equations (1) and (2).

For the implementation of the presented approach, following procedure is suggested:

Step-1: rollout related primary data collection (location details, installation type: Pilot/Regular, Other relevant data)
Step-2: network selection (WAN or NAN or HAN)
Step-3: economic classification of project site (Rural or Urban)
Step-4: fix up strength and classification of customers (Commercial/Residential/Industrial/Others)
Step-5: enlist smart grid applications decided for implementation (AMI, SCADA, MDMS, etc.)
Step-6: enlist wireless technologies to be examined (Cellular (GPRS/3G/4G LTE), Satellite (LEO), Wi-Fi, RF (2.4 GHz/868 MHz/915 MHz), WiMAX, Z-wave, etc.)
Step-7: implement optimization approach-Cost function based approach

Cost Function (CF)

$$CF_{ij} = \left(\frac{1}{\sum_{q=1}^{N_{KPiu}} W_{qi}} * \sum_{q=1}^{N_{KPiu}} (W_{qi} N_{qij}) \right) \tag{1}$$

Cost Function (CF) matrix

$$CF_{ij} = \begin{bmatrix} CF_{11} & \cdots & CF_{1i} \\ \vdots & \ddots & \vdots \\ CF_{i1} & \cdots & CF_{ij} \end{bmatrix} \tag{2}$$

Guidelines for decision-making:

(i) Opt and apply largest data rate and lowest latency values to generate strongly suitable wireless technology alternatives.
(ii) Cost function values are basis of selection. Smaller cost function values indicate that the capacity of that particular wireless technology is faithful to satisfy the required communication needs. Cost function values either negative or relatively high are not to be considered as they are indicating incapability of the particular wireless technology to cater the estimated communication needs.

3.2 Algorithm

In Table 1, an algorithm for the proposed optimization approach is presented. Data rate along with latency are the key performance indicators 1 and 2 respectively. Indices for smart grid applications and wireless technologies are i and j respectively; where $i \epsilon (1{:}N)$ and $j \epsilon (1{:}F)$. A cost function is formulated employing smart grid applications and wireless technologies. The cost function value is indicative of the particular wireless communication technology's capability to satisfy the particular smart grid application's communication needs. As the cost function value is smaller, it indicates the better capability of that particular wireless technology to fulfill the communication needs of the particular smart grid application. Negative and relatively very large cost function values indicate constraints and limitations of that particular technology to satisfy the application's communication needs and therefore ignored.

4 Case Study: The Siliguri City Indian Smart Grid Pilot

Siliguri city is located in the northeast state of West Bengal, India. The smart grid pilot is implemented by West Bengal State Electricity Distribution Company Limited (WBSEDCL) covering 5,265 customers with AMI, and PLM applications [7]. Considering as default requirements, we have also included SCADA and MDMS applications in this work.

Figure 2 depicts the graphical representation of the implementation of the optimization approach presented in Section 3.

4.1 Pilot Details

(i) Total no. of consumers: 5,265

Table 1 Algorithm for the proposed optimization approach

Input: opted applications, feasible wireless technologies
Output: optimal wireless technology alternatives

```
1:  Start
2:  define total number of opted applications as N with i as its index, $i \in (1:N)$
3:  define total number of feasible wireless technologies as F with j as its index, $j \in (1:F)$
4:  Compute weighted and normalized data rate values
    calculate $W_{DRij}$ and $N_{DRij}$ for ith application-jth technology combination
5:  Compute weighted and normalized delay values
    calculate $W_{delayij}$ and $N_{delayij}$ for ith application-jth technology combination
6:  calculate cost function for ith application-jth technology combination as per Equation (1)
7:  save $CF_{ij}$ to matrices as per Equation (2)
8:  $j = j + 1$
9:  if $j > F$, then set $j = 0$, go to 11
10: go to 4
11: $i = i + 1$, if $i > N$, then go to 12, else go to 4
12: call the matrix from 7
13: assign best-fit communication technology using CF as per Equation (2)
14: end
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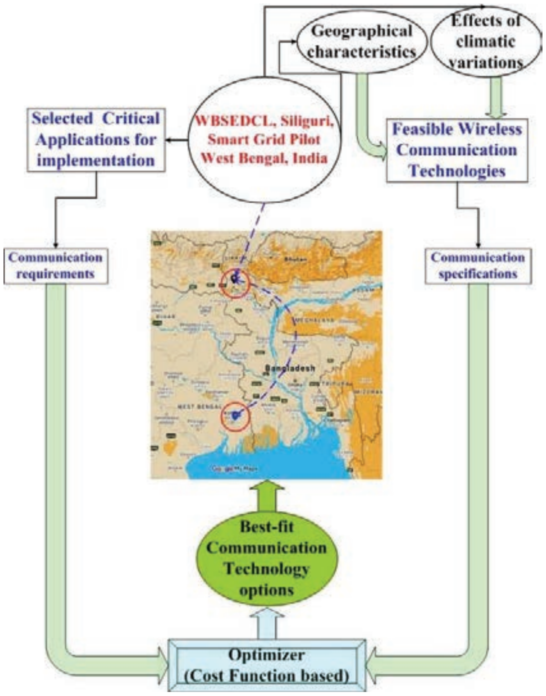


Figure 2 Graphical depiction of the implementation of the proposed optimization approach on the Siliguri city Indian smart grid pilot.

Table 2 Communication needs of smart grid applications [19]

Sr. No.	Smart Grid Application	Reference (UTC) Data Rate (kbps)	Reference (UTC) Latency (s)	Selected Data Rate (kbps)	Selected Latency (s)
1	AMI	10–100 (500 for backbone)	2 to 15	500	2
2	PLM	56	2	56	2
3	SCADA	10 to 30	2 to 4	30	2
4	MDMS	56	2	56	2

Table 3 Wireless communication technologies and their specifications [27]

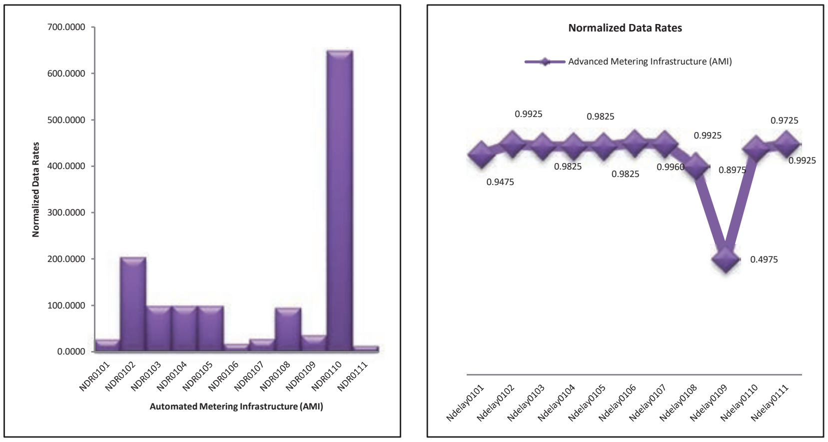
Sr. No.	Wireless Communication Technology	Reference (UTC) Data Rate (kbps)	Reference (UTC) Latency (s)	Selected Data Rate (kbps)	Selected Latency (s)	Spectral Efficiency (b/s/Hz)
1	Satellite (LEO)	1000	0.1	1000	100	1.8
2	Z-wave	40	0.01	40	10	0.243636
3	ZigBee (RF 868 MHz)	20	0.03	20	30	0.5
4	ZigBee (RF 915 MHz)	40	0.03	40	30	0.5
5	ZigBee (RF 2.4 GHz)	250	0.03	250	30	0.5
6	Wi-Fi	2000 to 600000	0.003	100000	3	2.7
7	WiMAX	75000	0.01 to 0.05	75000	10	1.73
8	Cellular 2G GSM	up to 14.4	0.2	14	200	1.36
9	Cellular 2.5G GPRS	40 to 50	0.7 to 1	50	1000	1.35
10	Cellular 3G	11000	0.05	11000	50	0.077
11	Cellular 4G LTE	300000	0.005 to 0.010	300000	10	3.6

(ii) Smart grid applications installed: AMI, PLM, SCADA, MDMS – Total 04 applications-communication needs are specified in Table 2 [19]. (SCADA and MDMS are included as default smart grid applications). Table 2 includes application wise reference values of data rate and latency suggested by UTC, and our selected values for this work.

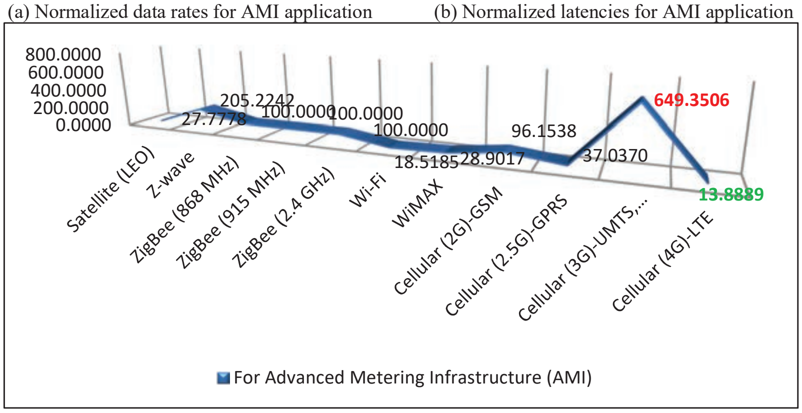
(iii) Wireless technologies to be examined: 11 technologies, specifications are mentioned in Table 3 [27]. Table 3 includes specifications of the wireless communication technologies such as data rate, latency, and spectral efficiency [27].

(iv) Sampling period: 15 minutes (04 samples/hour) or 30 minutes (02 samples/hour)

(v) Data packet size: 125 bytes or $\sim$1000 bits (1 kb)



(a) Normalized data rates for AMI application (b) Normalized latencies for AMI application



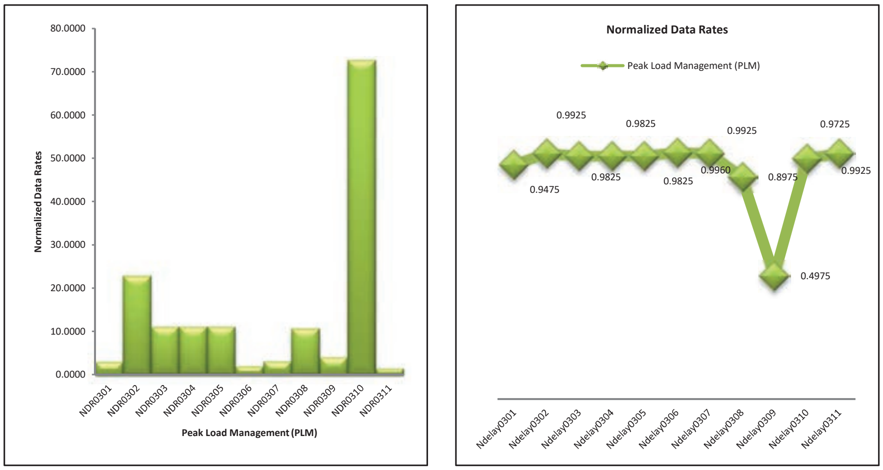
(c) Cost Function values for AMI application

Figure 3 Evaluation of AMI application for the Siliguri city Indian smart grid pilot.

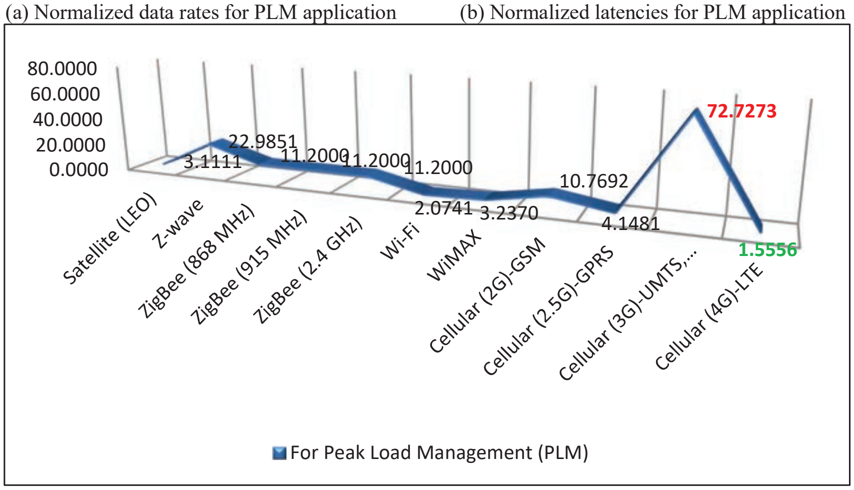
For obtaining robust results, we have selected largest possible values of data rates and lowest possible values of latencies in the specified reference ranges.

5 Results and Discussions

The results of the implementation of the proposed approach upon the Siliguri city smart grid pilot of India are discussed in this section along with their graphical illustrations. Smart grid application-wise and overall, cost function values are calculated, and based on their values; the top three best-fit



(a) Normalized data rates for PLM application (b) Normalized latencies for PLM application



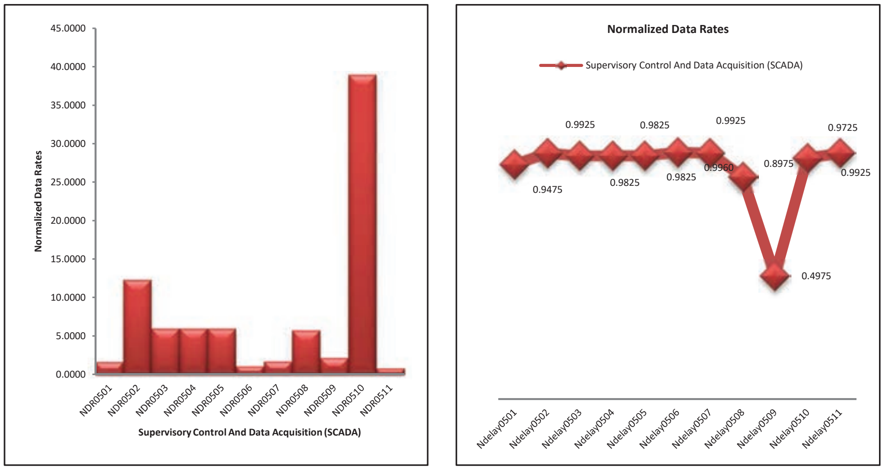
(c) Cost Function values for PLM application

Figure 4 Evaluation of PLM application for the Siliguri city Indian smart grid pilot.

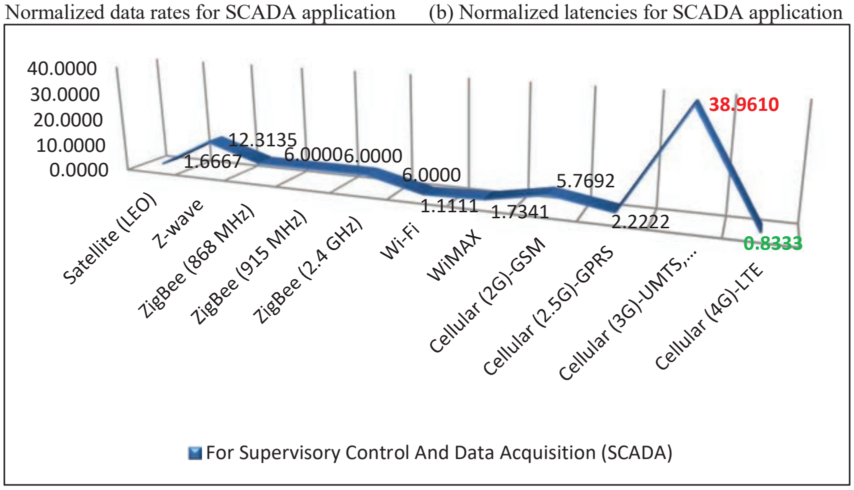
communication technologies options are recommended as summarized in Table 4.

5.1 Advanced Metering Infrastructure (AMI)

This is the essential application for every smart grid rollout. This application along with SCADA and MDMS forms the platform for the implementation



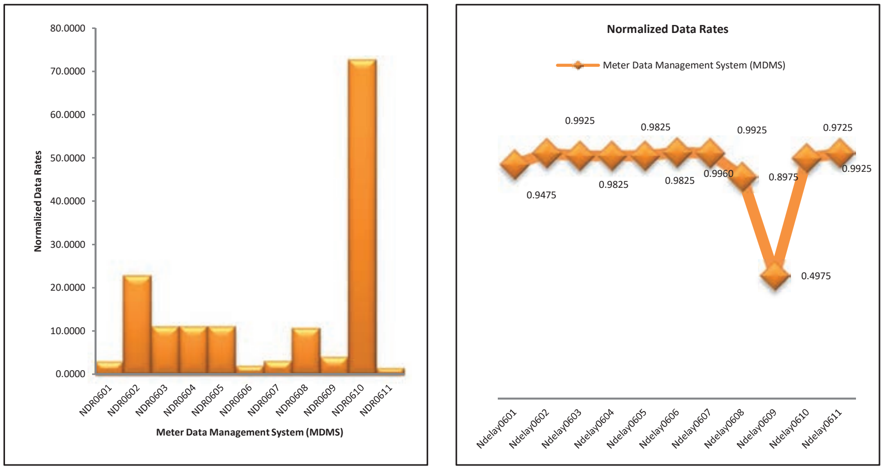
(a) Normalized data rates for SCADA application (b) Normalized latencies for SCADA application



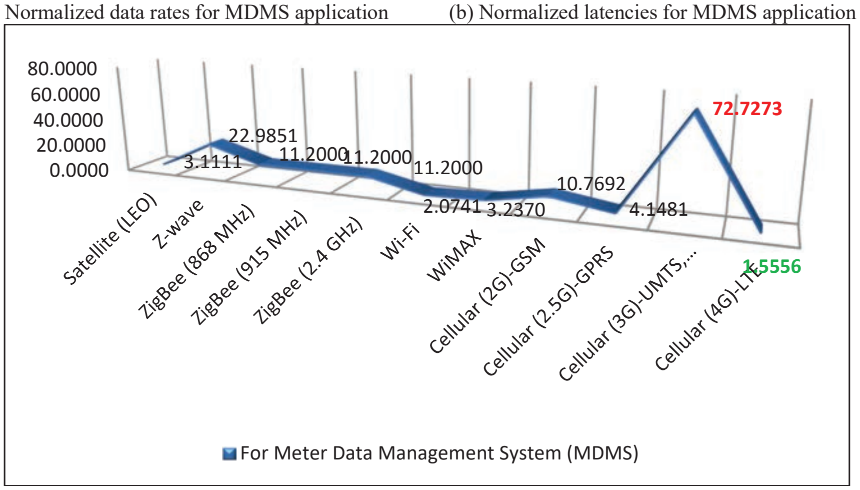
(c) Cost Function values for SCADA application

Figure 5 Evaluation of SCADA application for the Siliguri city Indian smart grid pilot.

of other smart grid applications. From the analysis of normalized data rates in Figure 3(a), normalized latencies in Figure 3(b) and cost function values in Figure 3(c), it could be observed that cellular 3G, Z-wave, and ZigBee (RF 868 MHz or 915 MHz or 2.4 GHz) technologies are the top three weak choices, while 4G LTE, Wi-Fi, and Satellite (LEO) are the top three strongest alternatives.



(a) Normalized data rates for MDMS application (b) Normalized latencies for MDMS application



(c) Cost Function values for MDMS application

Figure 6 Evaluation of MDMS application for the Siliguri city Indian smart grid pilot.

5.2 Peak Load Management (PLM)

From the analysis of normalized data rates in Figure 4(a), normalized latencies in Figure 4(b), and cost function values in Figure 4(c), it could be observed that cellular 3G, Z-wave, and ZigBee (RF RF 868 MHz or 915 MHz or 2.4 GHz) technologies are the top three weak choices, while 4G LTE, Wi-Fi, and Satellite (LEO) are the top three strongest alternatives.

Table 4 Summary of results of evaluation of the Siliguri city Indian smart grid pilot

Sr. No.	Smart Grid Application	Cost Function Value	Best-fit Technology Options	Final Aggregated Outcome
1	Advanced Metering Infrastructure (AMI)	13.8889 18.5185 27.7778	Best-fit 1: Cellular LTE 4G Best-fit 2: Wi-Fi Best-fit 3: Satellite (LEO)	Best-fit 1: Cellular LTE 4G Best-fit 2: Wi-Fi Best-fit 3: Satellite (LEO)
2	Peak Load Management (PLM)	1.5556 2.0741 3.1111	Best-fit 1: Cellular LTE 4G Best-fit 2: Wi-Fi Best-fit 3: Satellite (LEO)	
3	Supervisory Control And Data Acquisition (SCADA)	0.8333 1.1111 1.6667	Best-fit 1: Cellular LTE 4G Best-fit 2: Wi-Fi Best-fit 3: Satellite (LEO)	
4	Meter Data Management System (MDMS)	1.5556 2.0741 3.1111	Best-fit 1: Cellular LTE 4G Best-fit 2: Wi-Fi Best-fit 3: Satellite (LEO)	

5.3 Supervisory Control and Data Acquisition (SCADA)

SCADA is also the default application for every smart grid implementation. From the analysis of normalized data rates in Figure 5(a), normalized latencies in Figure 5(b), and cost function values in Figure 5(c), it could be observed that cellular 3G, Z-wave, and ZigBee (RF RF 868 MHz or 915 MHz or 2.4 GHz) technologies are the top three weak choices, while 4G LTE, Wi-Fi, and Satellite (LEO) are the top three strongest alternatives.

5.4 Meter Data Management System (MDMS)

MDMS is also the basic application for every smart grid installation. From the analysis of normalized data rates in Figure 6(a), normalized latencies in Figure 6(b) and cost function values in Figure 6(c), it could be observed that cellular 3G, z-wave and ZigBee (RF 868 MHz or 915 MHz or 2.4 GHz) technologies are the top three weak choices, while 4G LTE, Wi-Fi and Satellite (LEO) are the top three strongest alternatives.

The summary of the implementation of the proposed approach on the Siliguri Indian smart grid pilot is presented in Table 4. Application-wise cost function values of the top three best-fit wireless technology options are recorded.

From our analysis, it is observed that cellular technology LTE 4G, Wi-Fi, and Satellite (LEO) are found as the top three best-fit alternatives (in order of preference), on account of their relatively smaller cost function values, while the deployed cellular GPRS 2.5G and ZigBee technologies are found relatively quite incapable technologies, which is evident from their comparatively larger cost function values.

6 Conclusions

Given the importance of communication systems in the smart grid for the accomplishment of sustainable development goals, the requirement of selecting the best appropriate communication technology has been addressed. The difficulty of selecting the most suitable wireless technology is treated as a design problem of an instrumentation telemetry system. The issue is extensively investigated, with a focus on the efficient and successful deployment of smart grid applications. The best answer to the problem is offered in the form of a data-driven evaluation strategy for selecting the best technological solutions for decision-making. The proposed solution approach, which includes mathematical optimization approach and a decision-support tool for evaluating the capabilities of viable wireless technology options and suggesting the best suitable alternates, could be used at the design stage of an upcoming smart grid project.

The presented approach is tested by implementing upon the Siliguri Indian smart grid pilot and yielded encouraging outcomes. The evaluation of four smart grid applications implemented under the pilot is conducted for eleven wireless communication technologies. Finally, post evaluation, based on technical suitability and anticipated improvements, the deployed RF and GPRS technologies are deemed weak choices, whereas cellular LTE 4G, Satellite (LEO), Wi-Fi, and WiMAX are suggested as the best suitable options for replacement in the order of preference. The cost function values obtained after evaluation are summarized in Table 4 and are supportive of these findings.

The scope of the case study presented in this paper is confined to NAN only, which is generally implemented to bridge HANs and WANs. NANs are often expected and therefore designed to handle massive data traffic with huge data rates and strict delay constraints. Higher cost function values imply that the deployed communication technologies – RF and GPRS – are limited in their capacities. Their performance could deteriorate substantially in the future if the pilot is expanded to include all the consumers and applications. This work could be extended by including more performance metrics (besides data rate and latency), applications, and wireless technologies as well as for other networks such as HAN and WAN.

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Appendix – I: Abbreviations and Their Descriptions

Abbreviation	Description
AMI	Advanced Metering Infrastructure
CF	Cost Function
CPS	Cyber Physical System
DERS	Distributed Energy Resources and Storage
DGM	Distributed Generation Management
DR	Demand Response
GPRS	General Packet Radio Service
GSM	The Global System for Mobile communication
HAN	Home Area Network
HEM	Home Energy Management
HetNet	Heterogeneous Network
ITS	Instrumentation Telemetry System
KPI	Key Performance Indicator
LEO	Low Earth Orbit
LTE	Long Term Evolution
MCDA	Multi Criteria Decision Analysis
MDMS	Meter Data Management System
NAN	Neighbourhood Area Network
NSGM	National Smart Grid Mission
PHEV	Plug-in Hybrid Electric Vehicles
PLCC	Power Line Career Communication
PLM	Peak Load Management
PQM	Power Quality Management
Prosumer	Producer+consumer
RF	Radio Frequency
SCADA	Supervisory Control And Data Acquisition
SDG	Sustainable Development Goals

Abbreviation	Description
SGCS	Smart Grid Communication System
UTC	Utilities Telecom Council
WAN	Wide Area Network
WBSEDCL	West Bengal State Electricity Distribution Company Limited
WASA	Wide Area Situational Awareness
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access

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