NB-IoT Pervasive Communications for Renewable Energy Source Monitoring

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***Abstract*—Renewable sources like solar and wind energy have seen a drastic increase in the market, especially in developing countries where electricity prices are high and QoS and QoE, both are at their lowest. In this paper, we innovate by proposing a paradigm of smart off-grid from sensing using an Internet of Things (IoT) based smart meter for continuous monitoring, to reporting a daily user on their smart devices using IoT middleware. Our proposed smart off-grid system keeps track of the performance and faults of the off-grid equipment. Under communication technology scrutiny, we model 3GPP Narrow Band IoT (NB-IoT) collision and success probability of grouping smart meter communications to avoid random access channel (RACH) congestion. The proposed smart off-grid communications outperform existing systems and achieve 1.3 to 20 times higher SINR, more than 30 Mbps data rate in 4G, three times higher data rate in NB-IoT,** 25% **fewer collisions and** 25% **higher success rate.**

***Keywords*—NB-IoT; smart off-grid; RACH; 4G LTE**

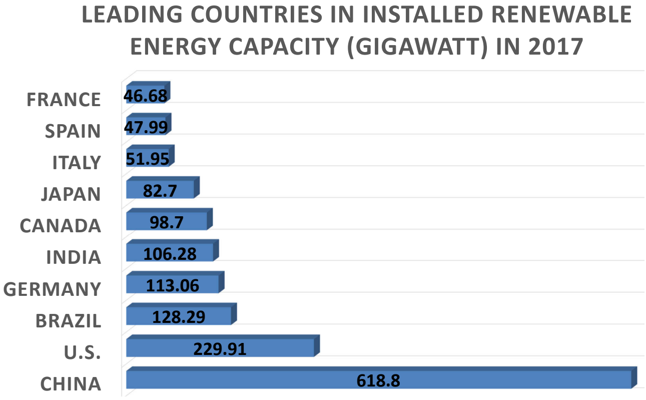

Fig. 1. Renewable energy capacity statistics

I. INTRODUCTION

Low cost and reliable energy sources have always been and will always be a major part of human interest. Users and investors are moving towards off-grid solutions like nuclear, wind and solar, powering 12-volt appliances from a bulb to an air-conditioner. Currently (in 2017), the worldwide installed RES capacity led by China accounts for more than 1500 gigawatt[1], as shown in Figure 1. Cheaper and easily manageable energy solutions attract more and more small-scale investors, suppliers and distributors, challenging the monopoly of traditional government electrical grids [1]. These off-grid systems not only produce energy but also reduce transmission losses and cost of production, distribution, and maintenance [2]. Work in [3] discusses a relay selection scheme for cellular networks, powered by green energy sources. However, the major goal is to reduce power consumption and dependency of cellular relay stations from traditional grids, the work is related to our proposed aggregation scheme for cellular network relays.

We propose smart meter based smart off-grid monitoring of RES using a number of sensors like moisture, light, motion, humidity, production, etc. and IoT middleware services/ servers. Installation of a number of smart meters, especially in urban areas requires communications network providers. Wi-Fi, Bluetooth, ZigBee, and other short-range communication technologies lack in range, internet, and prevalent service. On the other hand, the cellular networks have a widespread network with tons of base stations (BSs) having the range in kilometers and can be useful assets for the IoT communications. Moreover, the 3GPP standardized Narrow Band IoT (NB-IoT) with 4G Long Term Evolution (LTE) coverage characteristic with lower power consumption. However, the inherent random access channel (RACH) challenge persists. In NB-IoT communications, the device initializes the process after getting PRACH information from the SIB-2 message and transmits continuous repeated RACH. The BS responds by sending RAR message and receives message 3 from the device. The BS sends contention resolution message to the device and initiates subsequent communications and resource assignments. In case of any message failure, the device resends preamble after 12 ms. Unlike LTE, the RACH process messages are repeatedly sent between device and BS, illustrated in Figure 2. However, the collision or contention occurs similar to the LTE, if two or more than two devices send a request on the same randomly selected RACH. The contention burden is increased in the NB-IoT with repeated transmission occupying resources.

Authors in [4] describe that a device can withdraw its next scheduled transmission message if it gets unmatched Time Advance (TA) information of RAR and avoids possible request collision. However, there is still a lot of room to improve and reduce additional delays for the devices. Exhaustive study and observation of existing literature deduce that there is a need for an adequate and suitable architecture for smart RES management and control with continuous communications, which is not yet proposed. However, 5G network is embarking with a plethora of data rate to mobile devices but the delay intolerant IoT networks like smart grids and smart meters can make use of the 4G and NB IoT networks[5, 6]. On the

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[1] IRENA - Renewable Energy Capacity Statistics 2018, page 2-5

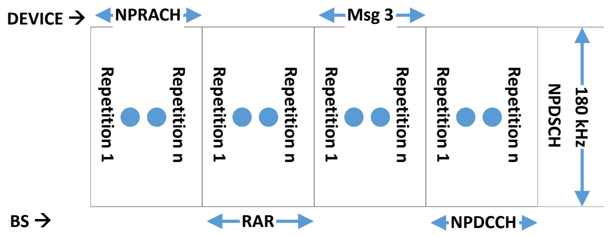

Fig. 2. NB IoT RACH procedure and structure

other hand, timely network connectivity becomes a critical need in a disaster situation [7]. We are the first to design and propose an outright architecture which not only discusses smart meter design and monitoring for RES but also tackles the communication challenges. Our major contribution and innovation over existing systems are:

1) design a smart meter and an innovative architecture for renewable sources
2) NB-IoT contention model with continuous monitoring of RES
3) higher signal-to-interference and noise (SINR) value by 20 times and reduced collisions and increase success by 25% over existing systems.

The rest of the article is organized as follows: Section 2 exhaustively discusses existing literature work on smart grids/ off-grid renewable systems and existing literature for the 4G LTE RACH and NB-IoT RACH issues.

Section 3 presents the proposed solution with smart meter design and proposed aggregation scheme. We analytically model SINR, collision and success probabilities with proof of concept. Performance evaluation and results are analyzed in Section 4. Section 5 concludes the paper.

II. LITERATURE REVIEW

In this section, study of exhaustive literature is discussed, providing useful insights on what has been achieved and things that are lacking in earlier smart off-grid systems and 4G LTE RACH solutions.

A. Smart Meter and Off-Grid

There are numerous aspects in our take on the smart off-grid system like designing a smart meter for continuous monitoring and contributing with an intelligent and distributed architecture for control of RES. Existing literature is sporadically diverse in the areas like the design of micro-grids, distribution planning of RES, decentralize control, energy scheduling, etc.

Research work on small-scale RES in [1] focus on contractual trading of stored energy for conflicts avoidance using energy informatics. The authors model a coalitional game for direct trading among suppliers with fair revenue division. However, the trading requires a centralized entity as an aggregator in the main micro-grid station. Authors in [2] propose a micro-grid design for RES and autonomous control overcharging or discharging of energy storage units. The proposed automation envisions to extract maximum power from the RES and provide quality power to the user. However, we plan to extend and provide deeper insights using a number of sensors and IoT middleware. Work in [3] discusses a relay selection scheme for cellular networks, powered by green energy sources. However, the major goal is to reduce power consumption and dependency of cellular relay stations from traditional grids, the work is related to our proposed aggregation scheme for cellular network relays. [8] introduce a multi-objective and multi-level model for the distribution system with RES and energy storage. The authors model RES and energy storage planning as an optimization problem using modified Pareto-based particle swarm optimization (PSO). Our proposed scheme can benefit [8] by providing pervasive and continuous monitoring and control. Another study in [9] model penetration of RES as multi-generator interconnected power network. The authors utilize a decentralized adaptive neural network feedback controller to stabilize dc link voltage oscillations during grid turbulence. The simulation and performance evaluation use IEEE 14-bus power system for damping oscillations after disturbances. However, the study lacks in automation and in continuous control by the users.

Flexible supply-demand management in [10] focus on optimal energy scheduling for residential smart grids. Authors provide a solution for cost-effective energy scheduling with a centralized RES. The study highlights the trade-off between RES energy and associated cost, and volatility of RES for optimal exploitation. However, a major drawback of the study is to consider centralized renewable sources which question the practicality of the work. [11] utilizes a quality of experience (QoE) based approach for RES management in the residential environment. Authors propose profile based QoE aware appliance scheduling and RES power allocation. A central controller communicates with individual smart meters to change operational state on or off of the appliances. Authors in [12] assume a scenario of a number of RES in a centralized network and propose to balance RES in a micro-grid using meteorological forecast for next 24 hour and plant location. The solution depends on the weather forecast to enable most productive RES for energy generation. However, unlike [12], we consider communication challenges of continuous monitoring and insights of the RES using middleware [13].

B. Random Access in LTE

Inherently, NB-IoT utilizes Orthogonal Frequency Division Multiple Access (OFDMA) for resource sharing over RACH. In an OFDMA slot, each device randomly selects a RACH and in a case of multiple devices selecting the same RACH, a collision or contention happens [14]. Figure 2 outlines the repetitive access communication flow between device and BS. Initially, a device chooses a RACH and requests for resources. The BS responds with a random access response (RAR) message, containing a unique identifier. In the subsequent scheduled transmission, the BS realizes that two or more than two devices have been assigned the same RACH. The BS drops the requests and the devices are required to request again after a random back-off period. This adds delays in the communications resulting in user frustration and could cause catastrophic results in delay-intolerant applications like vehicular or medical. With the increase in the access intensity the chances of collision increase.

TABLE I. LITERATURE REVIEW OF SMART RES AND RACH SOLUTIONS

Literature	**Research Focus**	**Major Details**
Smart Off-Grid Solutions		
Zhiyong Li et.al [1]	Small scale RES trading	● Fair revenue and division model using coalitional game formulation ● Provides optimal consumption, prices and profit results
S.K. Tiwari et.al [2]	Design and control of micro-grid	● Autonomous RES control system ● Automatic charging and discharging
Hui-Ju Hung et.al [3]	Cellular relay selection with green energy	● Relay selection ● Reduced power consumption of relay stations. ● Use of green energy for relays.
Rui Li et.al [8]	Cooperative distribution system	● RREs and energy storage planning and distribution ● Optimal solution using Pareto-based PSO
Shaghayegh Kazemlou et.al [9]	Decentralized RES control	● Decentralized controller for RESs and energy storage units ● Neural network controller
Yuan Wu et.al [10]	Optimal energy scheduling	● Cost effective and optimal exploited RES system ● Centralized RESs and energy storage units
Virginia Pilloni et.al [11]	Smart home energy management	● Smart meter based appliance energy controller ● Profile based approach for energy management
Mattia Marinelli et.al [12]	Predictive control strategy for RES	● Weather based forecast and RES control ● Day ahead energy planning
Existing RACH solutions		
Kab Seok Ko et.al [4]	Time alignment Matching	● Collision avoidance. ● Applicable only for overlapping area.
Farhadi et.al[15]	Group based signaling (aggregation)	● Device aggregation to reduce RACH competition ● Frequency reuse utilization. ● Possesses grouping overhead.
Chang et.al [16]	Machine-to-Machine data gathering	● A novel data perspective of Machine-to-Machine Communication. ● Incompatibility with large number of Machine-to-Machine.
Zheng et.al [17]	Prioritized Human and Machine Type Communications	● Extreme prioritization techniques ● Each techniques focuses only one type of communications ● Causes longer delays.
Huasen et.al [18]	Interrupted Poisson Distribution	● Active devices estimation in cellular system ● Device barring and congestion reduction. ● Causes longer delays.
Shao-Yu Lien et.al [19]	Cooperative access barring	● Barring parameter selection using Multiple eNB information ● Possesses less overhead. ● Applicable only for overlapping area.
Tzu-Ming Lin et.al [20]	Dynamic ACB with device classification	● Five categories for incoming traffic ● Dynamic access class barring utilization. ● Strategic, static approach.
Hasan et.al [21]	Q learning at device end	● Utilization of Q Learning in device ● Collision avoidance.

Authors in [4] describe that a device can withdraw its next scheduled transmission message if it gets unmatched Time Advance (TA) information of RAR and avoids possible request collision. Work in [15] propose to reduce uplink requests by aggregating device requests. Initially, each device communicates to one another and selects a group delegate which corresponds to BS. Frequency reuse in the different group of devices increases the spectral efficiency within the same BS. However, the solution requires a great deal of frequency reuse and grouping management. Another similar work in [16] groups the devices and aggregate the uplink requests to reduce contention. The article models the size of the group as the NP-Hard problem and suggests two approaches, Cross Entropy-based randomized approach, and Tabu Search. However, the solution is more focused on the group size problem than reducing RACH contentions. Another research in [17] evaluates two scenarios of Prioritized Human-Type-Communications and Prioritized Machine-Type-Communications to highlight the extreme communication procedures.

Authors of [18] discuss an Interrupted Poisson Distribution estimation approach for active user's calculation in the network. The number of active users, help in reducing RACH competition by device barring in the subsequent slot. On the other hand, the barred or delayed devices suffer from additional delays. [19] proposes a barring approach, where Access Class Barring (ACB) is improved to a cooperative design. Cooperative ACB gains 30% higher success over ACB, but a number of devices suffer from additional delays. Work in [20] outline five classes of incoming traffic and applies Dynamic Access Barring (DAB) mechanism to reduce RACH competition. The solution prioritizes the devices and adds delays to the traffic in three different scenarios of low, medium and high. [21] suggests Q-Learning experience based BS selection by the devices. The solution implicates devices in overlapping areas to have prior knowledge of BS. Standardization organizations like 3GPP have included ACB and Extended ACB mechanism to reduce collisions in LTE cellular networks [22]. However, there is still a lot of room to improve and reduce additional delays for the devices.

Table I outlines existing literature on state of the art solutions and ideas related to the smart grid and RESs. The table also includes existing solutions to tackle RACH congestion in communications resource access. Exhaustive study and observation of existing literature deduce that there is a need for an adequate and suitable architecture for smart RES management and control with continuous communications, which is not yet proposed. The strength of most of the existing solution is to enable a barring or prioritized system. We are the first to design and propose an outright architecture which not only discusses smart meter design and monitoring for RES but also tackles the communication challenges.

Fig. 3. Proposed paradigm of smart off-grid

III. SMART OFF-GRID SOLUTION USING IOT

Our design of smart meter considers a number of sensors like humidity, motion, etc. for continuous monitoring of the RES equipment. We propose that the information is then fed to a middleware service like ThingSpeak[2], which not only provides data storage but also generates interactive graphs for deeper insights. Moreover, a mobile application or a web app can utilize ThingSpeak REST API to read the accessible and authorized data. Each communication message between a user and an RES equipment requires middleware server (ThingSpeak) and communications network. Figure 3 highlights middleware communications with the RES monitoring architecture over NB-IoT and 4G. The number of smart meters increases the access intensity in NB-IoT and 4G LTE RACH causing delays and the proposed scheme counters that by aggregating several smart meter requests. We propose that each device identifies itself as an aggregator using a boolean check variable Aggregator. If the device is an aggregator, it accepts the data, accumulates all messages and requests for RACH. On the contrary, the device broadcasts request to nearby devices, selects the first response of candidate aggregator and send data for accumulation.

A 4G BS shares resources using a number of random preambles which are accessed by the devices. Let V={v_1, v_1, ..., v_k} be the total number of k devices, cuncurrently requesting to the 4G BS for the (M) RACH resources. Assuming that each of the devices compete with an equal opportunity, the collision probability (P_α) and success probability (P_β) in the legacy network is desribed by [4] as:

$$P_\alpha = 1 - \left(1 - \frac{1}{M}\right)^{k-1} \tag{1}$$

Algorithm 1 Smart meter aggregation algorithm

```
if Aggregator==True then
    Receive and acknowledge messages from neighboring smart meters
    Request for RACH
    Aggregate and send data
else
    Broadcast aggregator request and store Acknowledgments.enqueue(acknowledging address)
    if Acknowledgments=! $\emptyset$ then
        Send data to device at Acknowledgments.dequeue()
    else
        Aggregator=True
    end if
end if
```

$$P_\beta = \left(1 - \frac{1}{M}\right)^{k-1} \tag{2}$$

Moreover, the 4G LTE uplink Signal-Interference-plus-Noise-Ratio (SINR) (δ_α) of a smart meter with k other devices with P transmission power, g channel gain, and μ Additive White Gaussian Noise off a quasi-static Rayleigh fading channel, is described in [5] as:

$$\delta_\alpha = \frac{gP}{\mu + \sum_{n=1}^{k-1} g_n P_n}\,, \tag{3}$$

where interference by other k devices is represented by $\sum_{n=1}^{k-1} g_n P_n$.

The data rate (ψ_α) with BW bandwidth of 4G network, can be estimated as:

$$\psi_\alpha = BW \log(1 + \delta_\alpha) \tag{4}$$

Let R_B be the coverage radius of a BS and R_S be the range of an aggregating smart meter. If another smart meter is randomly placed in the radius of the BS then the probability of its placement within the range of an aggregator can be calculated as $P_\rho = \frac{\pi {R_S}^2}{\pi {R_B}^2}$. We can extend the probability for randomly placed λ aggregators, as:

$$P_\rho = \frac{\sum_{a=1}^{\lambda} \pi {R_{S,a}}^2 - \left[\left(\sum_{b=1}^{\lambda}\sum_{c=1}^{\lambda} \pi {R_{S,b}}^2 \cap \pi {R_{S,c}}^2\right)/2\right]}{\pi {R_B}^2} \tag{5}$$

Because, the aggregators are randomly placed, they can overlap each other. Above equation first calculates total radius of all λ aggregators as $\sum_{a=1}^{\lambda} \pi {R_{S,a}}^2$. Subsequently, the overlapping radius points are substracted using second part, $\left[\left(\sum_{b=1}^{\lambda}\sum_{c=1}^{\lambda} \pi {R_{S,b}}^2 \cap \pi {R_{S,c}}^2\right)/2\right]$. Combining both parts give us total favourable outcomes which then divided by total possible outcomes $\pi {R_B}^2$ estimates probability of a randomly

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[2] ThingSpeak is the open IoT platform with MATLAB analytics. Online: [https://thingspeak.com/]

placed smart meter within the range of an aggregator. However, for better understanding and simplicity of complex equation, we assume that the aggregators are disjoint to each other, which makes second term of above equation $\left[\left(\sum_{b=1}^{\lambda}\sum_{c=1}^{\lambda}\pi {R_{S,b}}^2 \cap \pi {R_{S,c}}^2\right)/2\right]$ equal to 0. Moreover, it also puts a constraint that to total radius points of λ aggregators must not exceed the total possible outcomes, i.e. $\sum_{a=1}^{\lambda}\pi {R_{S,a}}^2 < \pi {R_B}^2$.

Considering that there are k devices randomly placed within a BS, the total number of devices in λ aggregators can be estimated as:

$$\rho = \frac{\sum_{a=1}^{\lambda}\pi {R_{S,a}}^2}{\pi {R_B}^2} \times k + \lambda \tag{6}$$

Considering that the proposed aggregation reduces the access intensity by ρ devices, the collision probability (P_γ) and success probability (P_ω) in the proposed architecture can be estimated as:

$$P_\gamma = 1 - \left(1 - \frac{1}{M}\right)^{k-1-\rho} \tag{7}$$

$$P_\omega = \left(1 - \frac{1}{M}\right)^{k-1-\rho} \tag{8}$$

Moreover, the reduced competition also reduces the interference in the network, ergo the SINR in the proposed system (δ_β) becomes:

$$\delta_\beta = \frac{gP}{\mu + \sum_{n=1}^{k-1-\rho} g_n P_n}\ , \tag{9}$$

Subsequently, better SINR (δ_β) increases the data rate (ψ_β) for a device in the proposed paradigm with same BW bandwidth. Mathematically:

$$\psi_\beta = BW \log(1 + \delta_\beta) \tag{10}$$

The proposed system provides lower collision and higher successful access to the devices in the presence of smart meters. Our claim stands if following hypothesis holds true: $X = \frac{Proposed\ Collision\ Probability}{Existing\ Collision\ Probability} = \frac{P_\gamma}{P_\alpha} > 1$. Replacing values of P_γ from Equation 7 and P_α from Equation 1 in the equation, gives:

$$\left[X = \frac{1 - \left(1 - \frac{1}{M}\right)^{k-1-\rho}}{1 - \left(1 - \frac{1}{M}\right)^{k-1}}\right] > 1 \tag{11}$$

Applying $log[X]$ and reducing:

$$\left[\begin{array}{l}\log[X] = (k-1-\rho) \times \log\left[1 - \left(1 - \frac{1}{M}\right)\right] - \\ (k-1) \times \log\left[1 - \left(1 - \frac{1}{M}\right)\right]\end{array}\right] > 0 \tag{12}$$

TABLE II. SYMBOLS AND SIMULATION PARAMETERS

Symbol	Description	Simulation Value
k	Number of users	25-250
M	Number of available resources (RACH)	64
BW	4G LTE, NB-IoT	20 MHz, 180 KHz
ρ	Number of aggregated users	N/A
λ	Number of aggregator	4-20
P_α	Collision probability in existing system	N/A
P_β	Collision probability in proposed system	N/A
P_γ	Success probability in existing system	N/A
P_ω	Success probability in proposed system	N/A
δ_α	SINR in the existing system	N/A
δ_β	SINR in the proposed system	N/A
ψ_α	data rate in the existing system	N/A
ψ_β	data rate in the proposed system	N/A
P	Transmission power	250mW
g	Channel gain	15 dBi
μ	Additive White Gaussian Noise	-101 dBm
R_B	Range of 4G base station (BS)	500m
R_S	Range of smart meter aggregator	50m

$$\left[\begin{array}{l}\log[X] = \log\left[1 - \left(1 - \frac{1}{M}\right)\right] \times \\ \left[(k-1-\rho) - (k-1)\right]\end{array}\right] > 0 \tag{13}$$

$$\left[\log[X] = \log\left[1 - \left(1 - \frac{1}{M}\right)\right] \times -\rho\right] > 0 \tag{14}$$

The term in above equation ($\log\left[1 - \left(1 - \frac{1}{M}\right)\right] \times -\rho$) will always provide a positive value where $\rho > 1$ and $M > 1$. It should be noted that in every possible scenario, a BS will have more than one resources (M) and more than one aggregations (ρ). Thus proving $\log[X] > 0 \Rightarrow X > 1 \Rightarrow P_\gamma > P_\alpha$, where $\rho > 1$ and $M > 1$. It is safe to assume that a similar hypothesis also holds true for success probability and SINR values.

IV. PERFORMANCE EVALUATION

Our Monte-Carlo simulation based experiments and results for the existing and proposed system includes a total of 25 to 250 devices and 64 RACH preambles (M) for 20 MHz (LTE) and 180 KHz (NB-IoT) bandwidth (BW) based 4G LTE BS with 500 m communications radius [23]. The number of aggregators is defined between 4 to 20, having 50 m radius each, outlined in Table II. Each device/ smart meter is programmed to have a 250 mW transmission power, 15 dBi channel gain and -101 dBm noise factor. Comparative analysis is carried out using existing legacy system benchmarks presented in [4] and [5]. The existing legacy models are implemented with similar parameters and on similar Monte-Carlo simulation settings.

The increase in the number of requests and devices impacts the network performance. Assume a scenario of crowded urban environment where people are almost continuously communicating through mobile devices. Thus, increasing the accessing intensity and RACH collision which result in packet drops and additional delays. These delays become critical in delay intolerant applications. Our system aggregates the requests automatically and reduces the access intensity without barring any device. Figure 4 shows that the proposed smart

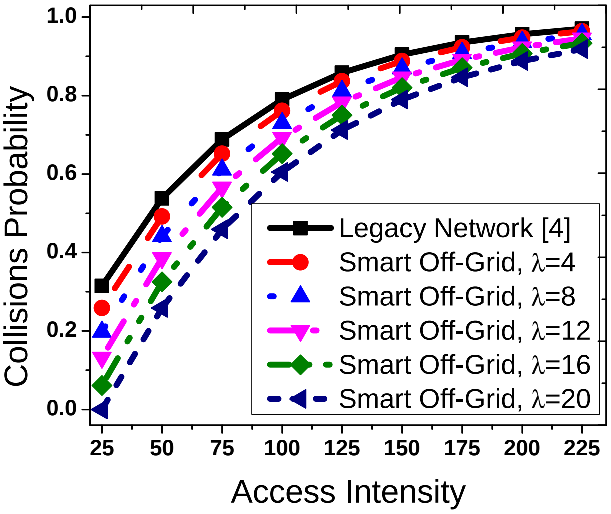

Fig. 4. Collision probability in the proposed and legacy system

off-grid system reduces collision probability by 5% to 25% for 4 to 20 aggregators. The existing collision probability is calculated using Equation 1 and proposed collision probability is estimated using Equation 7. The legacy network suffers from higher collisions due to the increase in the number of devices, whereas, the proposed smart off-grid reduces access intensity by aggregating requests. However, the increase in access intensity equally impacts both systems and increases collisions.

Figure 5 illustrates that the proposed system provides access to all devices at access intensity equals 25. The results for existing and proposed success probabilities are estimated using Equation 2 and 8. The successful resource allocation reduces in the proposed scheme with the increase in the number of devices. However, the proposed scheme outperforms the legacy system by 25% success probability. Figure 6 highlights the SINR gain of the proposed scheme over the existing network using Equation 3 and 9. The number of aggregators (λ) has a huge impact on the SINR value. The proposed scheme with 4 to 20 aggregators achieves approximately 1.3× to 20× gain over the legacy system. Figure 7 shows that the increase in devices equally impact on legacy network and proposed scheme with all variations. With a bandwidth of 20 MHz BW and only λ=4, the proposed scheme outperforms the legacy system by ~ 2 Mbps. The increase in the value of λ increase the performances of the proposed scheme, i.e. with $\lambda = 20$, the data rate soars high as 43.97 Mbps. The channel quality indicator (CQI) of devices impact bandwidth distribution, ergo reducing data rate per device. Considering NB-IoT limited bandwidth of 180 KHz, we have experimented the data rate for 25 to 250 devices, competing against each other. NB-IoT specific evaluation in Figure 8 also present similar facts that the proposed scheme outperforms the legacy system by providing three times higher value.

A. Complexity Analysis

The time and order complexity of proposed aggregation algorithm in a best-case scenario includes that the device is aggregator and shares only one message. In response, receives neighboring messages and request for RACH. Thus, using Big-O notation, the total complexity of the best case scenario is $O(1) + O(N) + O(1)$. On the other hand, if the device is not an aggregator, it requests to all neighboring devices ($O(N)$) and receives all possible acknowledgment, but chooses the first response. Nevertheless, the total complexity becomes $O(N) + O(N) + O(1)$. In both cases, the number of devices plays a major role to increase complexity but this number also increase the chances of successful aggregation. Thus, the message exchange becomes acceptable for all those devices requiring a successful connection and communications.

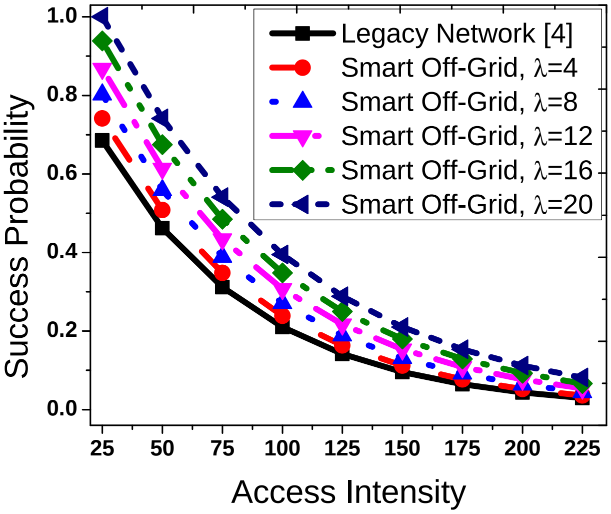

Fig. 5. Success probability in the proposed and legacy system

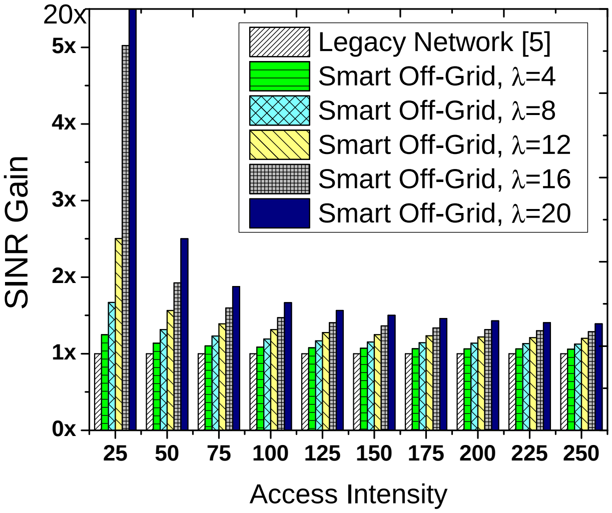

Fig. 6. SINR gain in the proposed and legacy system

V. CONCLUSION

This article presents and provides a complete architecture and communications paradigm to keep track of distributed RES equipment. Our major contributions include exhaustive literature review and innovative solution. We propose to continuously keep track of the performance and efficiency of the RES equipment using a smart meter. Our innovative smart meter not only tracks the energy generation but also monitors the

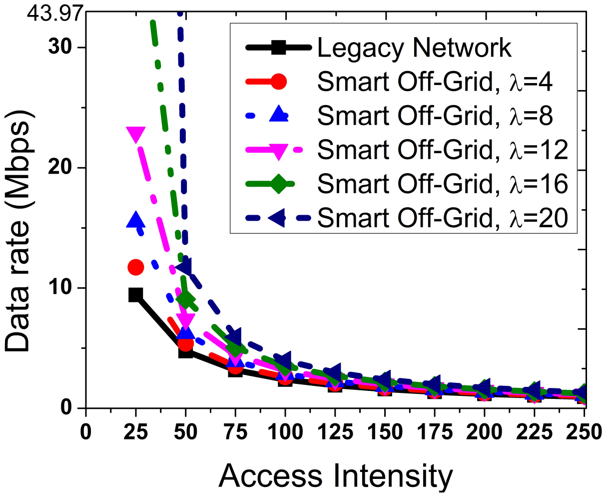

Fig. 7. Data rate of 4G LTE in the proposed and legacy system

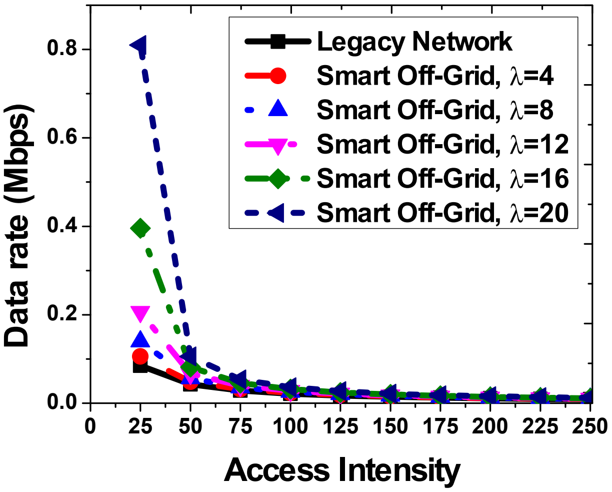

Fig. 8. Data rate of NB-IoT in the proposed and legacy system

health of the equipment. Moreover, the communication model for pervasive communication over NB-IoT is modeled and an aggregation scheme is presented. Our analytical model and respective proof of concept corroborate our claims of pervasive communications over 4G LTE and show clear advantages over the existing systems. Smart meter aggregation in NB-IoT and 4G environment achieve 25% reduced collisions and increased success probability. The communication also gains 1.3 to 20 times higher SINR value and three times higher data rate for a device (in LTE and NB-IoT, both), which leads to uninterrupted access. Our work and mathematically tractable equations pave a bridge to the co-existence of the NB-IoT in LTE and future 5G communications network. Moreover, in a device-centric architecture the trustworthy cooperation and aggregation of the devices is also a major future work.

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