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A Blockchain-based Framework for Energy Trading between Solar Powered Base Stations and Grid

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Introduction

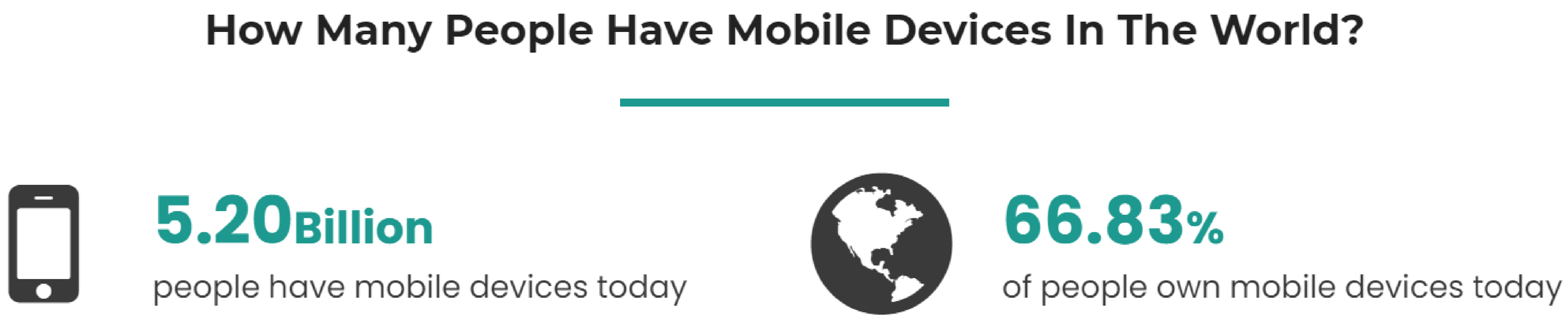

Figure 1: How Many People Have Mobile Devices in the World? (Source: GSMA Real-Time Intelligence Data, 2020) [1]

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The Problem

Rapid increase in the number of cell users → Increased mobile traffic → Increased number of cellular base stations

- Increased dependence on bad-grid and off-grid cellular base stations
- Mostly depend on diesel generators for energy requirements
  - increase in the operating cost
  - increased carbon footprint

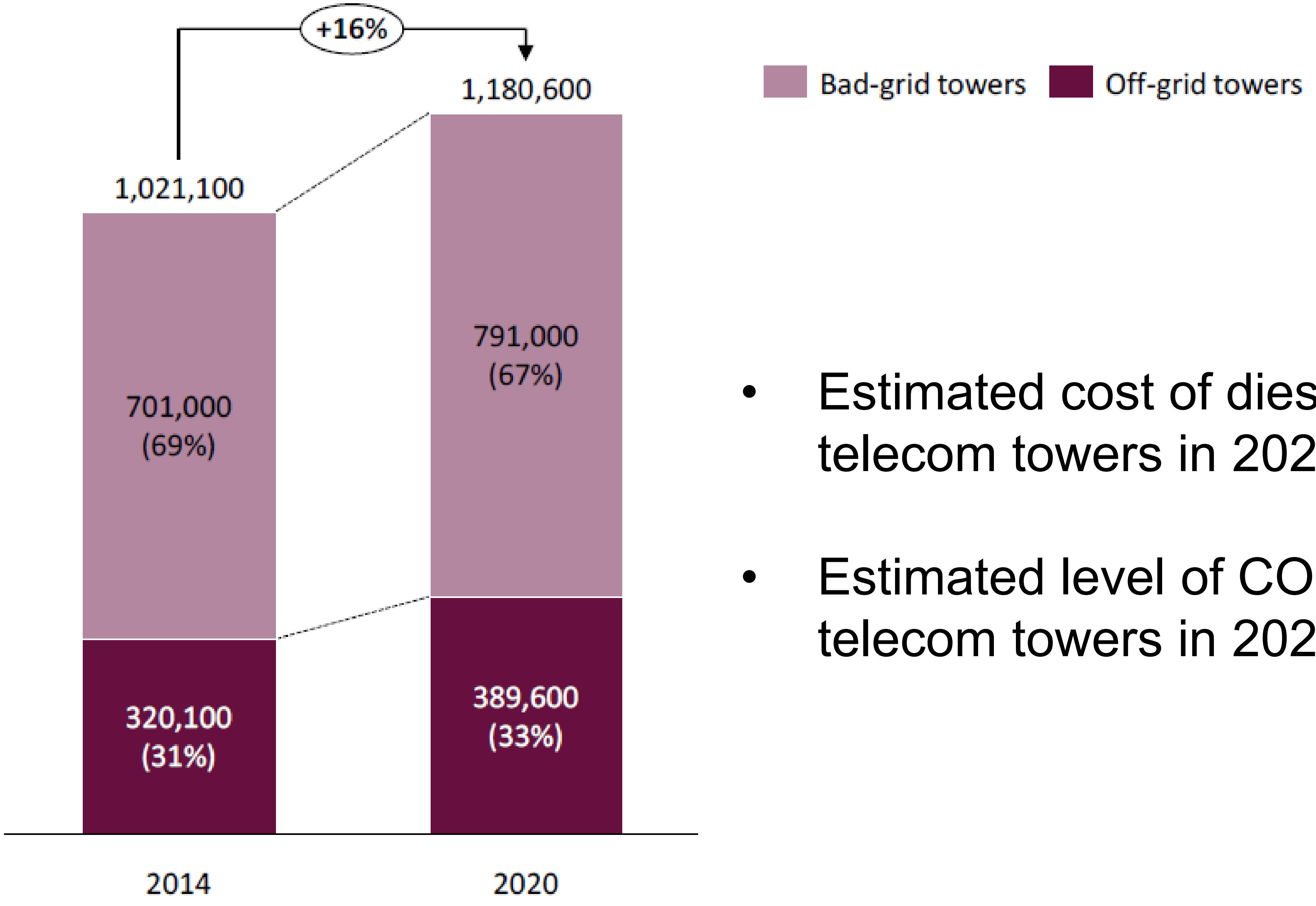
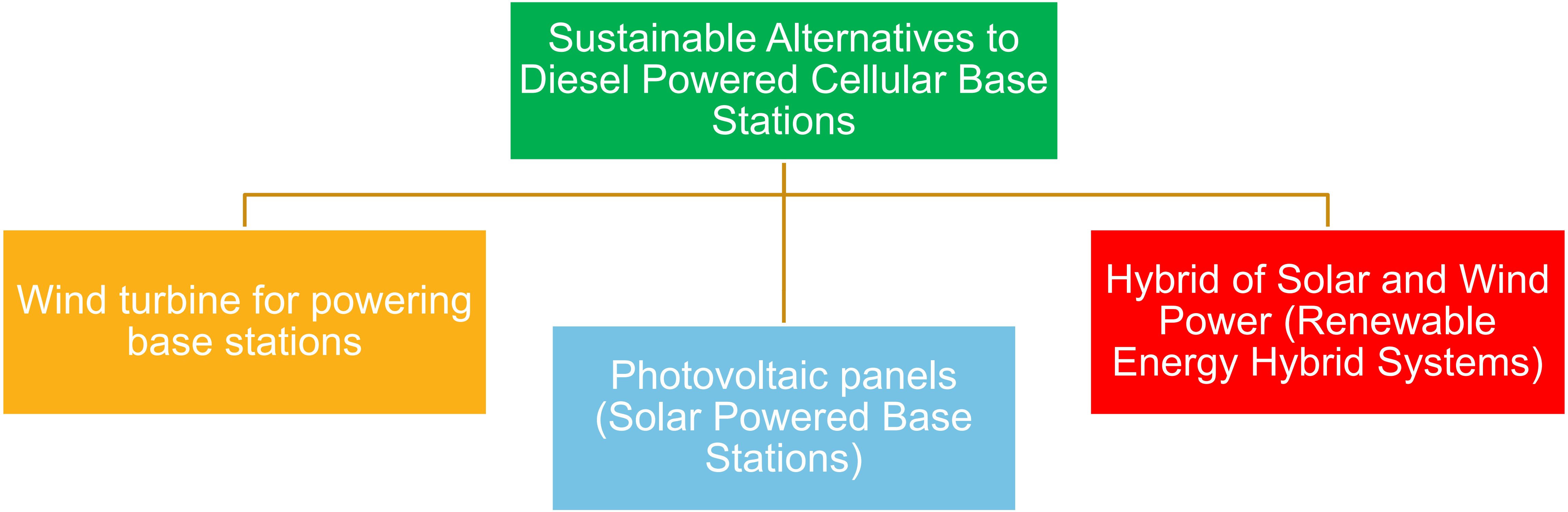


Figure 2: Total number of off-grid and bad-grid towers (Source: GSMA Green Power for Mobile Report, 2014) [2]

- Estimated cost of diesel for powering telecom towers in 2020: **US $19 billion**
- Estimated level of CO2 emissions from the telecom towers in 2020: **45 million tons**

Solution?

Cellular base stations powered by renewable energy sources such as solar power and wind have emerged as one of the promising solutions to these issues.



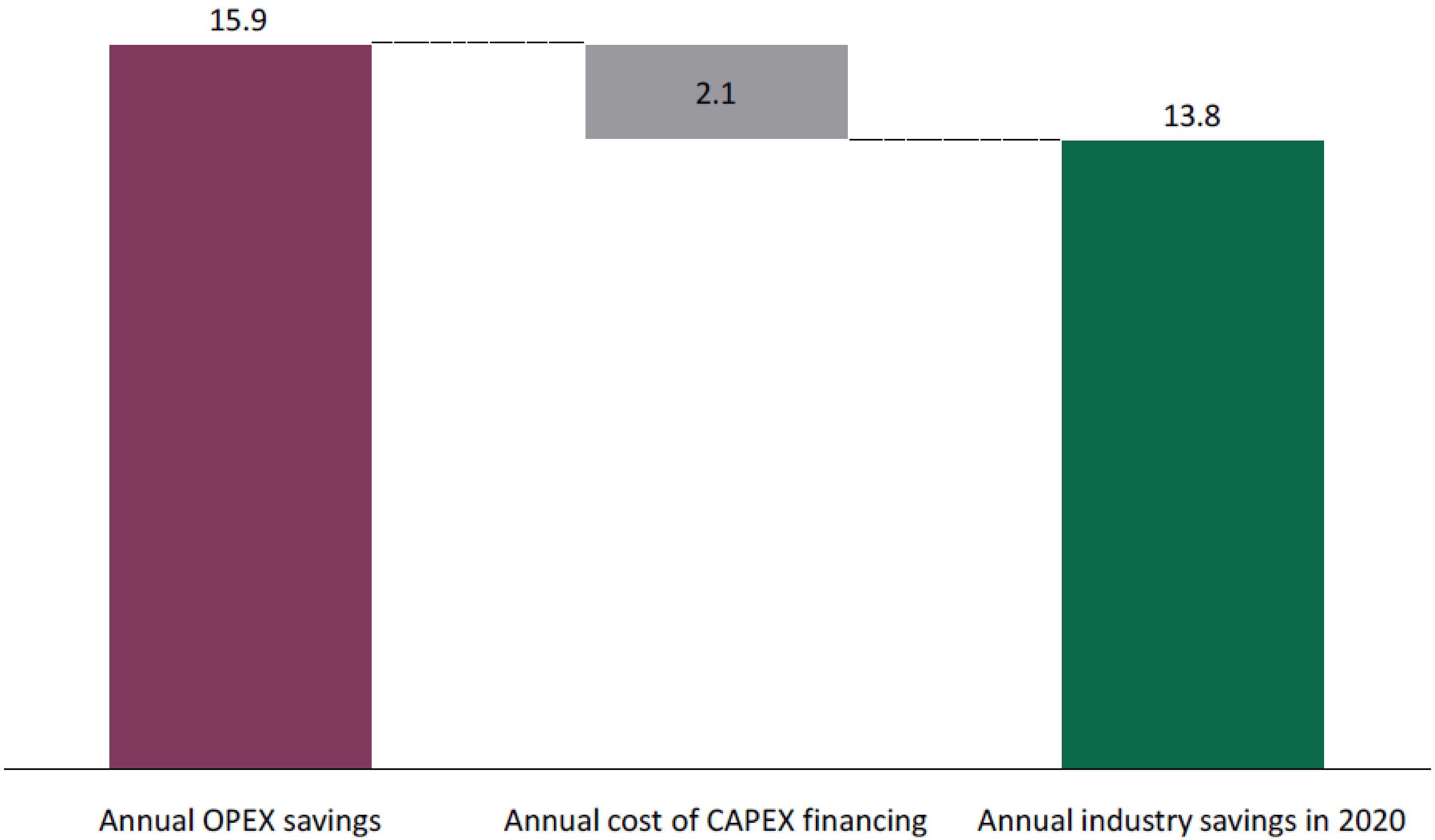


Figure 3: Annual industry cost savings due to transition to green energy solutions in Billion US$ (Source: GSMA Green Power for Mobile Report, 2014) [2]

Related works in this direction…

- Solar-Powered Base Transceiver Station (2018)
  - Wisnu Wahyu Wibowo et al.

- Towards zero grid electricity networking: Powering BSs with renewable energy sources (2013)
  - Marco Ajmone Marsan et al.

- Modeling renewable energy production for base stations power supply (2016)
  - Gowri Sankar Ramachandran et al.

Solar Powered Base Stations (SPBSs) Advantages

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Advantages of SPBSs over conventional base stations:

- make smart, sustainable and green by reducing the reliance of off-grid BSs on diesel generators for their energy requirements.
- can be implemented with lower capital cost
- solar power is widely available in developing regions such as the Indian subcontinent and African countries which have majority of the off-grid base stations.

Figure 4: A Solar-Powered Base Station (Source: Google Images)

However…

In remote areas, particularly in low mobile-traffic areas, solar power utilized by the SPBSs is often less than the solar power generated. Some of the excess energy is stored locally by the SPBSs for emergency purposes, but most of it is wasted.

Proposed Solution

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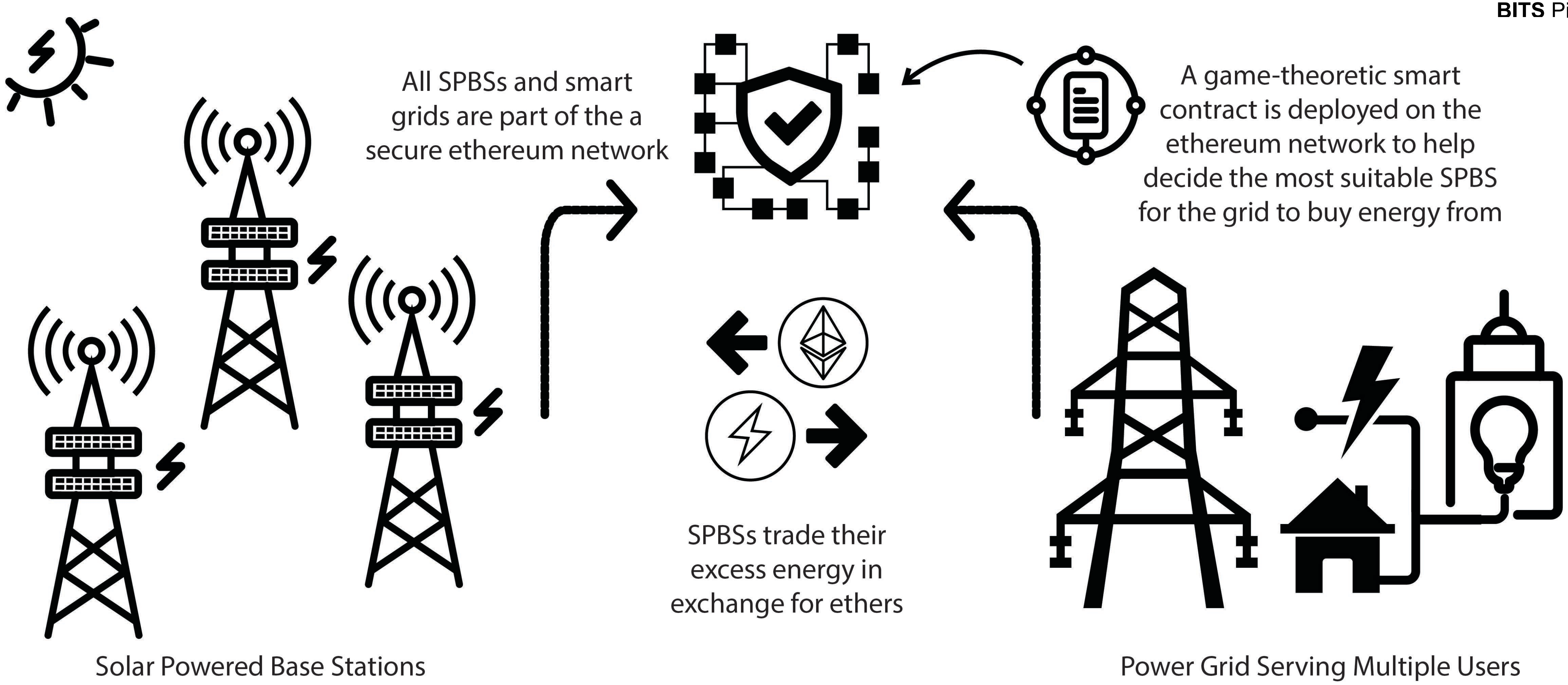

Figure 5: A Blockchain-based Framework for Energy Trading between Solar Powered Base Stations and Grid

Smart Grid

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Cutting-edge power grid technology with the potential to facilitate energy trade.

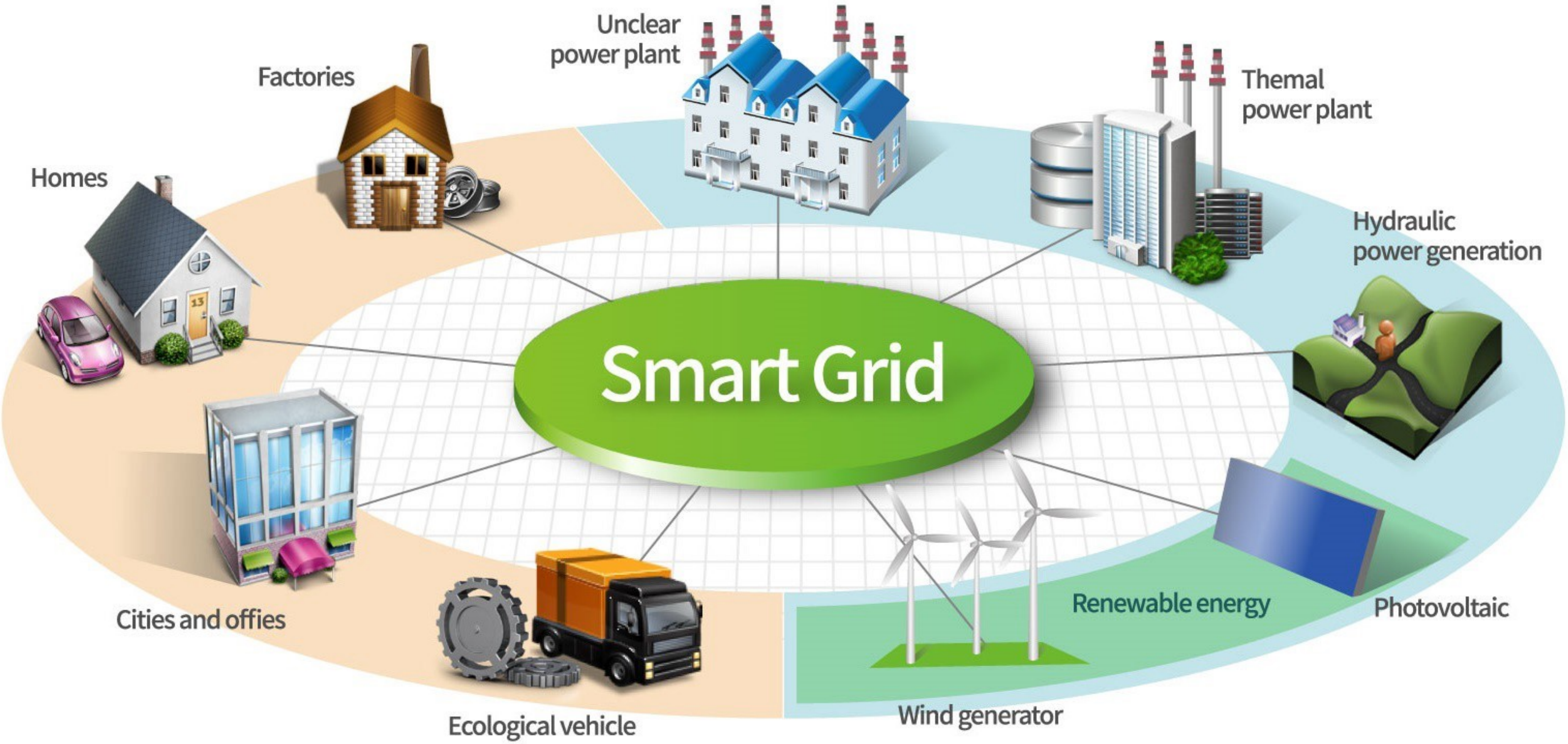
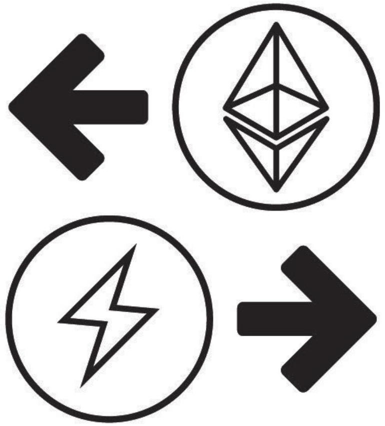


Figure 6: Integration of smart grid in different domains (Source: Google Images)

Base Station-to-Grid (BS2G) network

A framework to allow solar-powered base stations to trade their excess energy with the electric grid in exchange for some monetary benefit.



SPBSs trade their excess energy in exchange for ethers

Existing Energy Trading Frameworks…

- A Game-Theoretic Approach to Energy Trading in the Smart Grid (2014)
  - Yunpeng Wang et al.

- Energy Trading In the smart grid: A game theoretic approach (2015)
  - Naouar Yaagoubi et al.

- Recent Advances in Local Energy Trading in the Smart Grid Based on Game-Theoretic Approaches (2019)
  - Matthias Pilz et al.

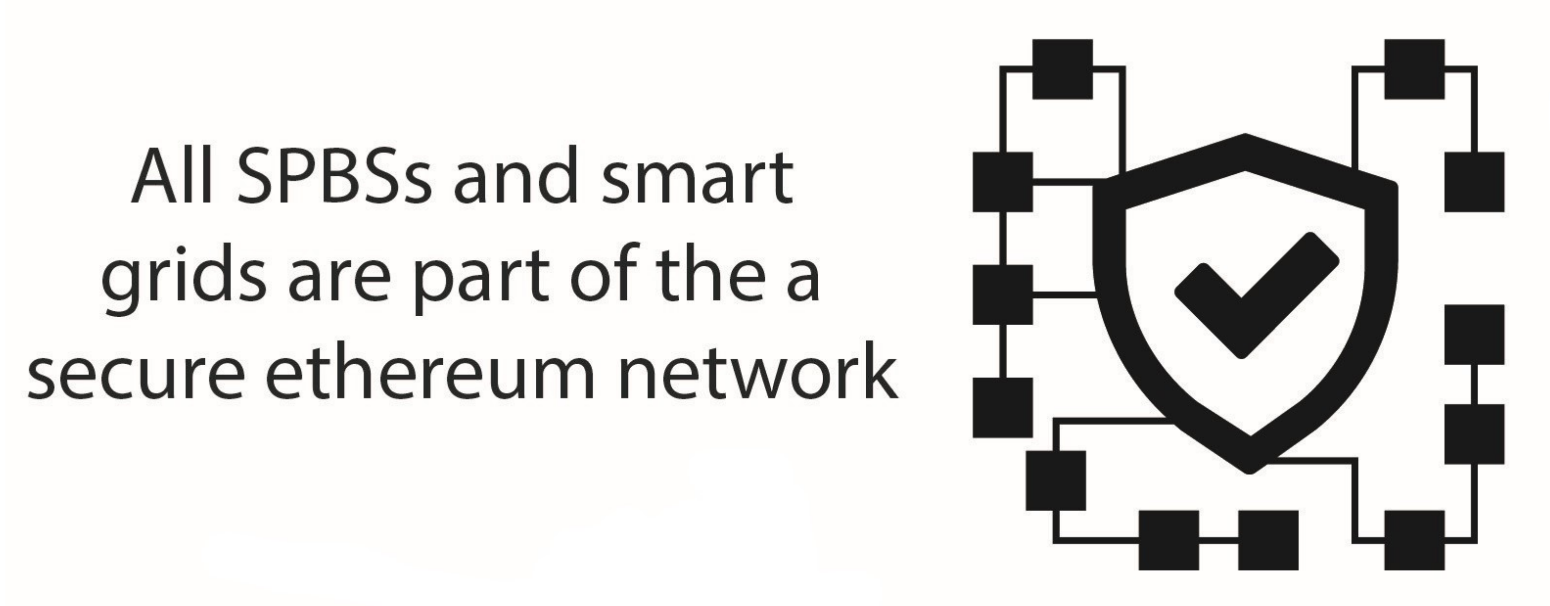
Issues in existing frameworks…

- Centralized servers may act as single point of failure
- Centralized databases are not feasible for frequent micro transactions
- Lack of transparency
- Scalability issues

Solution Identified: Blockchain

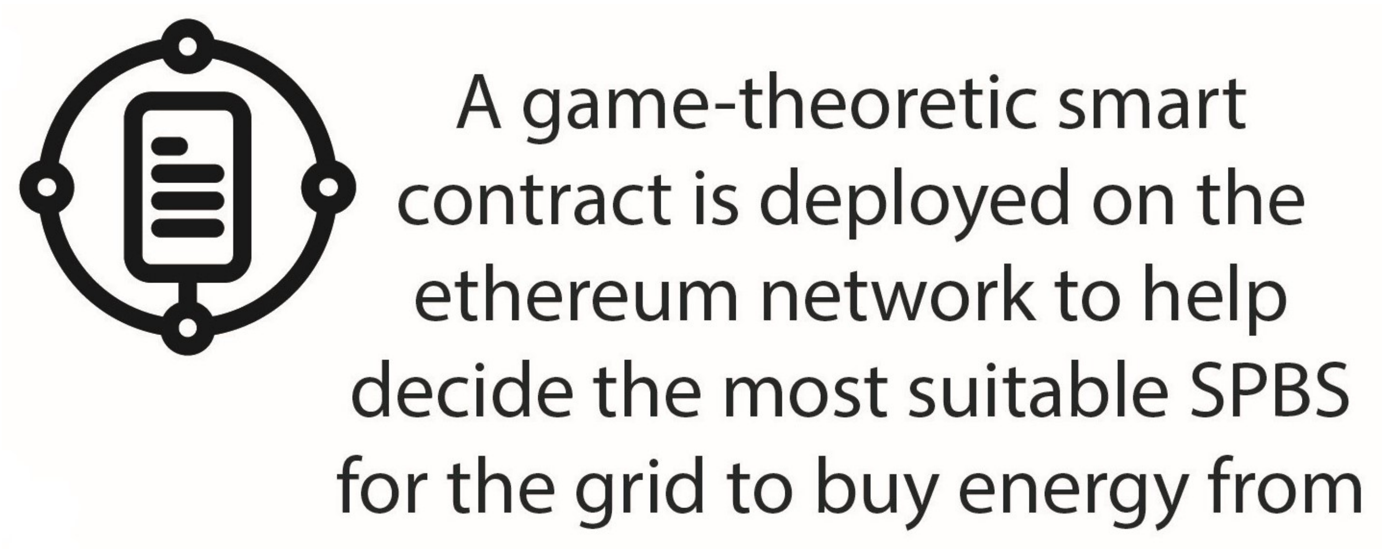
A Distributed ledger designed to record transactions in a transparent, lightweight, and tamper-proof manner.

- Scalable
- Robust
- Immutable



Game Theoretic Smart Contract

To model the energy trade between base station and the grids, we propose an evolutionary game between the participants.



Why Evolutionary Game Theory (EGT)?

- Classical theory' assumes that every player has knowledge of all sets of strategies and payoff functions.
- No penalty incurred by participants for not knowing strategies of other players.
- Rational decision making from the participants is not a prerequisite.

System Model

In our work, we consider a network that comprises of multiple solar-powered base stations and smart grids. In the proposed model, each base station and grid can act as both a producer and a consumer. Expenses may vary with the generation and consumption of energy owing to conditions such as:

- Climate
- Time of the Day
- Balanced Electricity Grid

BS2G Network Architecture

- All base stations and smart grids are part of the network.
- An unbiased party (smart contract) is deployed across the network.
- Smart contract is executed at each instance of energy trading.
- Power generation and power consumption profile of all network participants is maintained by the smart contract.

$$S_i = \{S_i^1, S_i^2, \ldots, S_i^{24}\}, \quad i \in \mathcal{P}$$

$$G_j = \left\{G_j^1, G_j^2, \ldots, G_j^{24}\right\}, \quad j \in \mathcal{Q}$$

Power generation profile of SPBSs and grids respectively

Classifying buyers and sellers

- Only BS2G exchange is modelled.
- SPBS may supply energy only if the energy it holds exceeds the minimum storage threshold.

minimum amount of energy that an SPBS should store in its batteries for emergency purposes

$$\theta_i^t = S_i^t - \left(S_i^{t'} + \theta_{min,i}^t\right)$$

Amount of energy that the SPBS can deliver during the t^{th} timeslot

Minimum storage threshold

Game theory in the BS2G Model

- evolutionary game theory-based smart contract
- each base station continuously changes its strategy to win the energy trading task
- smart grids employ the evolutionary game to select the most beneficial base station to buy energy from
- each grid's selection procedure is adjusted gradually
- grids independently select a solar-powered base station during the selection process

Simulation Settings

- Solar power generation profile of an 8 kW peak power photovoltaic (PV) base station has been taken from [3].
- The power load profile for a remote telecom base station has been taken from [4].
- Hourly power generation profile of the PV base station has been averaged over the month with least power generation.
- We consider the Rinkeby test network, consisting of 4 SPBSs and 2 grids to simulate our game-theoretic smart contract.
- Every SPBS can trade energy with any one of the grids in exchange for ethers (cryptocurrency).
- To verify the scalability of the proposed solution, we have used the Titan XP GPU to run the model.

Results

Figure 7 demonstrates the hourly power consumption profile of a remote telecom base station as well as the solar power production profile of a solar powered base station. It can be inferred from the graph that even though solar power is available for a limited number of hours, the amount of solar power generated in those hours is more than sufficient to account for the power unavailability during the rest of the day.

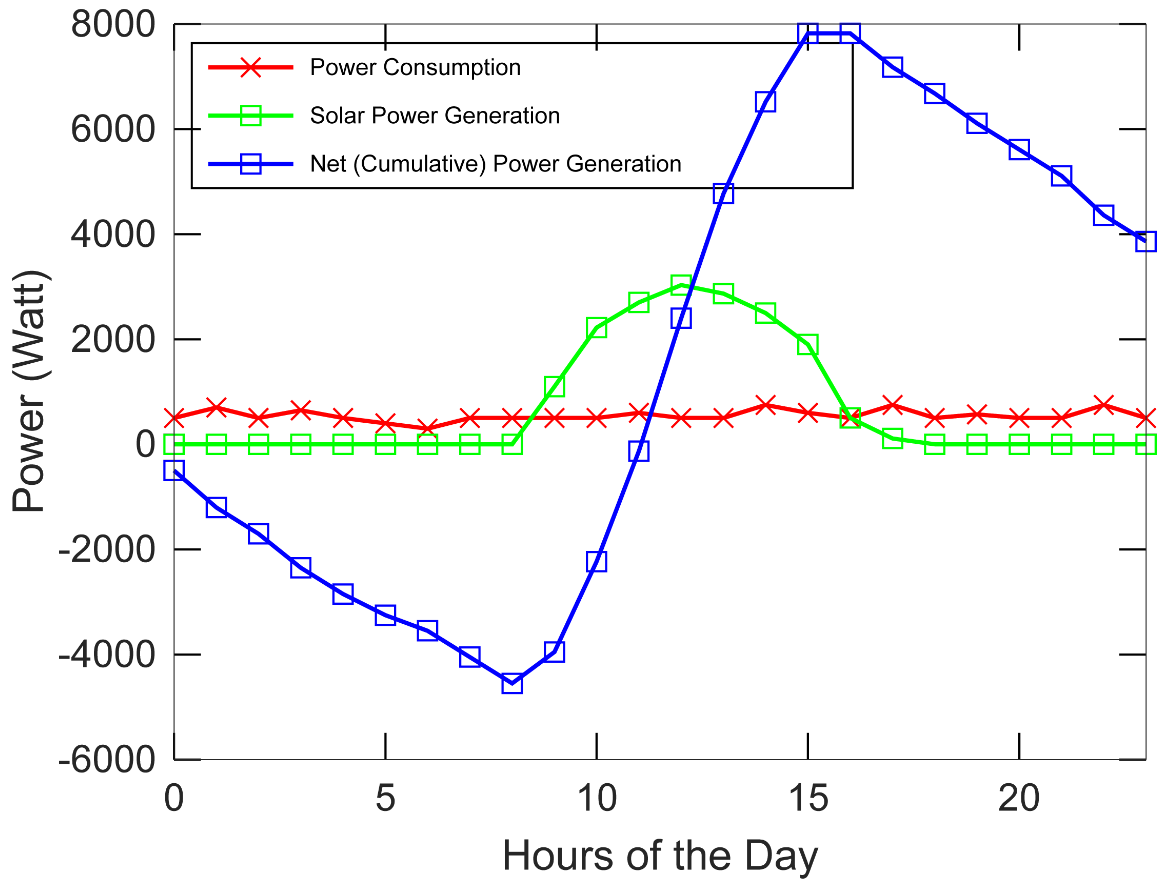


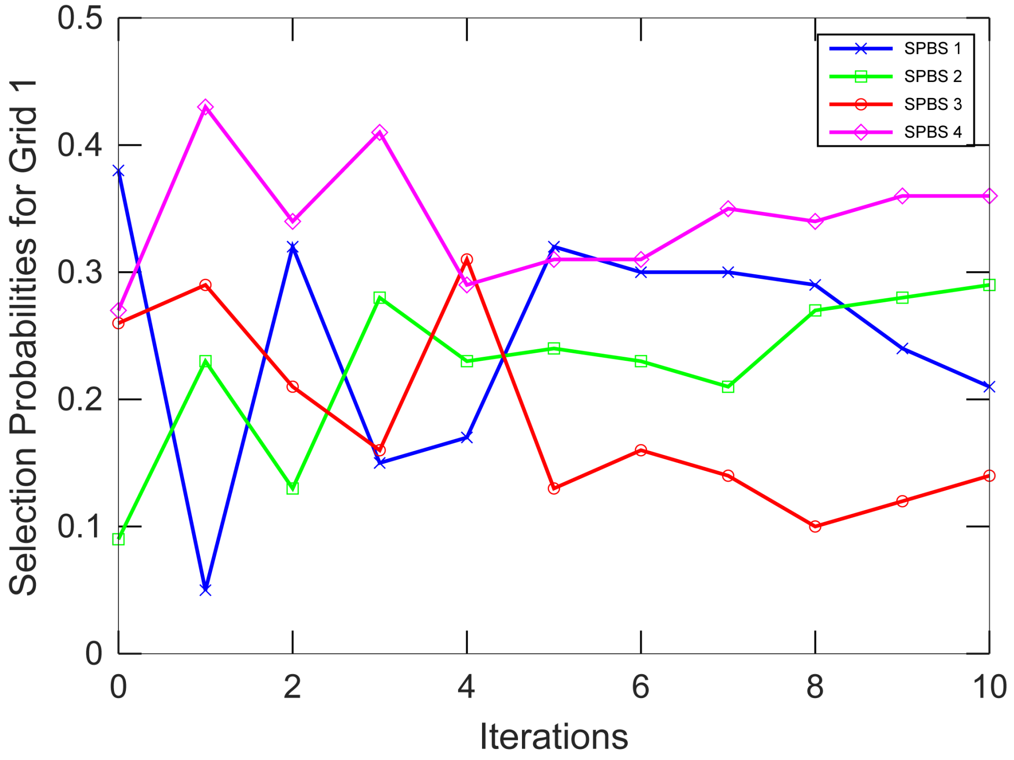
Figure 7: Power Profile of an SPBS

Some Calculations…

- **8 kW** peak production SPBS → **5 kW** of solar power every hour on avg.
- Taking into account immediate power consumption → **4 kW** of excess solar power
- Assuming a pack of **12V 200 Ah lead acid batteries → 12*200 = 2400Wh** energy to recharge a single battery completely.
- Assuming that batteries have **70% depth-of-discharge (DoD)**, the energy requirement falls to **2400*0.70 = 1680Wh**.
- Assuming battery's efficiency is 80% → energy requirement: **1680/0.80 = 2100Wh**
- 8 batteries in a single pack → energy requirement: **8*2100 = 16800Wh.**
- For an SPBS with a 4 kW rating → charge time: **16800Wh/4000W = 4.2 hours**.
- **These calculations show that an SPBS with access to six hours of sunlight could lose as much as two hours worth of solar power in a single day.**

*It is important to note that these calculations have been carried out, keeping in mind the values for a low-traffic remote base station.

Figure 8 shows the variation in probabilities of a particular SPBS getting selected by the grid. Initially, the selection probabilities are random. However, over multiple iterations, the selection probabilities converge to their optimal value. The algorithm assigns a higher selection probability to the base station with more favorable prices. The optimal values of probabilities are achieved when the grids achieve a stable state where they no longer change their selection strategy. Such a stable condition is referred to as an evolutionary stable strategy.



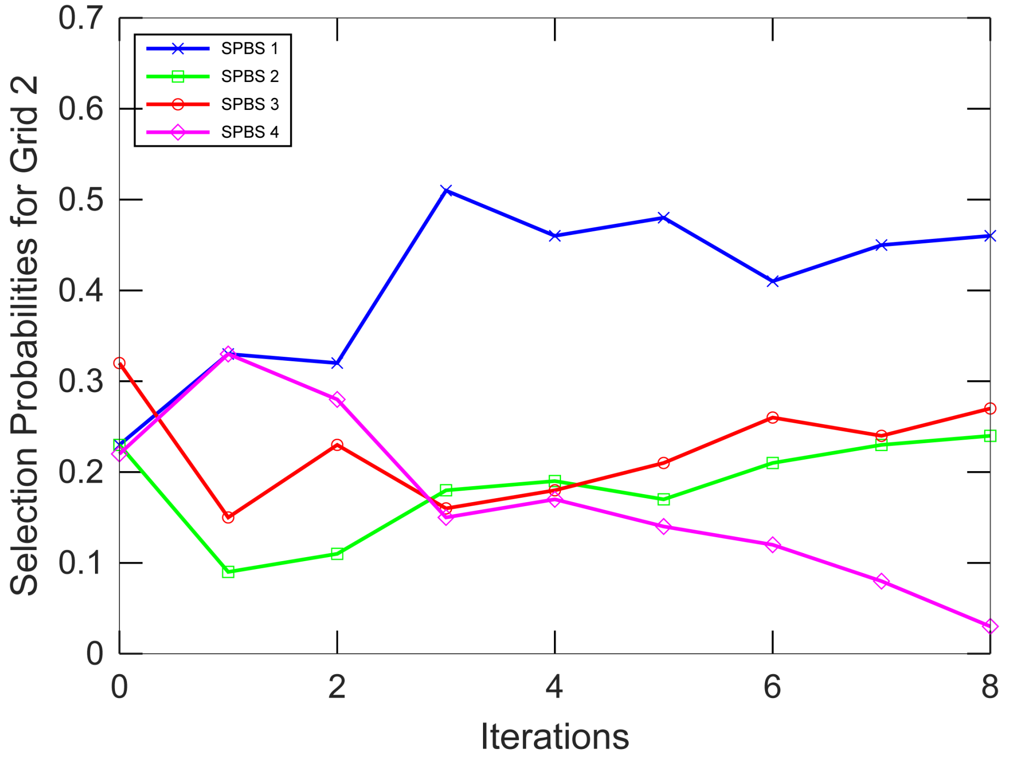


Figure 8: Variation in Selection Probabilities over Multiple Iterations

Conclusion

- A blockchain-based BS2G framework has been purposed.
- Blockchain data structure has been used to counter the limitations of traditional centralized architectures.
- An evolutionary game theory has also been implemented.
- EGT iteratively calculates every grid's selection probabilities corresponding to all the SPBSs before converging to the optimal selection probabilities.
- A game-theoretic smart contract is deployed on the ethereum network to ensure security and transparency while energy trading.

Future Work

- Here, we only model the BS2G exchange. The work can further be extended to model BS2BS, G2BS and G2G networks.

- In the future, we might consider a private network enabled with other consensus algorithms that are more effective in terms of computation.

- Lastly, the security claims of our model rest on the claims of the ethereum distributed ledger. In the future, the security aspect of our model may be evaluated more comprehensively.

References

[1] Ash Turner, "How Many Phones are in the World?", 2020, Available [Online]: https://www.bankmycell.com/blog/how-many-phones-are-in-the-world

[2] GSMA, "Green Power for Mobile", Dec. 2014, Available [Online]: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2015/01/140617-GSMA-report-draft-vF-KR-v7.pdf

[3] Marco Ajmone Marsan, Giuseppina Bucalo, Alfonso Di Caro, Michela Meo, and Yi Zhang. 2013. Towards zero grid electricity networking: Powering BSs with renewable energy sources. In 2013 IEEE International Conference on Communications Workshops (ICC). 596–601. https://doi.org/10.1109/ICCW.2013.6649303

[4] Mohammad Junaid Khan, Amit Kumar Yadav, and Lini Mathew. 2017. Techno economic feasibility analysis of different combinations of PV-Wind-Diesel-Battery hybrid system for telecommunication applications in different cities of Punjab, India. Renewable and Sustainable Energy Reviews 76 (2017), 577–607.

Thank you