Skoltech
Skolkovo Institute of Science and Technology

Thesis Changes Log

Name of Candidate: Tatiana Chernova

PhD Program: Engineering Systems

Title of Thesis: Peer-to-peer energy market design and operation: a constrained optimization perspective

Supervisor: Assistant Professor Elena Gryazina

The thesis document includes the following changes in answer to the external review process.

I want to express my gratitude to both internal and external reviewers, who put much effort into reading the thesis scrupulously and making useful comments and suggestions. I am happy to address the comments and questions in this document and in the revised version of the thesis.

Prof. Dipti Saxena

Suggestion to the candidate for improvement of the thesis

1. The scholar should cite reference, along with the figure title, if the figure is taken from some literature, for example, cite the reference in Figure 1-1.
   Thank you for the comment. We have searched for missed citations, and have added a reference for Figure 1-1.

2. The full form of the abbreviations is not uniform throughout the thesis. The scholar is advised to make it uniform, either "Capitalize each word" or "Sentence Case."
   We appreciate the comment. Abbreviations have been unified.

3. The research scholar may avoid capitalizing words in the middle of sentences for example, "Thesis" should be replaced by "thesis" if it is in the middle of a sentence. The same correction may be done for other words throughout the thesis.
   Thank you for pointing this out. We have replaced "Thesis" with thesis, and have searched for other similar cases.

4. The scholar should use subsections for example in section 5.4, different headings can correspond to different subsections, similarly for subsection 2.2.7 it should be done.
   Thank you for the precise remark. We apply different headings and indication by numbers in section 5.4, 2.2.7 as well as section 4.2. using numbering where it was absent The subsections have been highlighted more clearly using different headings and numbering where it was missing for ease of understanding.

5. Correct the inverted comma, punctuation section 3.1.1, second and third line
   We appreciate the comment. Quotation marks have been modified.

Queries, Questions, and points to be responded by the candidate at the time of Viva-voice

1. In the proposed optimization-based P2P market schemes, how do user preferences(like generation type and CO_2 footprint) affect trading patterns?
   We appreciate the comment. In the proposed methodology we exploit a regularization function approach to introduce preferences and assign an additional cost to the undesired trades in the form $\beta_{nm}p_{nm}$, where β_{nm} represent preference coefficients. The work mostly focuses on the distance-based preference – a preference to trade with the neighboring agents to support on-place generation and local neighborhood. The influence of such kind of preferences can be studied through the comparison of trading schemes in figure 3-2 and figure 3-3. The change of distance unit fee influenced the number and the value of the trades in the considered zone suggesting that the proposed way to introduce preferences works. Although the study of the preferences related to the type of generation were not in our focus we touched on this while modeling the joint presence of energy storage systems and user preferences (figure 4-5). In this case, we observe the absence of trade with undesired agent with high CO_2 footprint in favor of other agents. Generally speaking generation-type preferences (as any other preferences) could change the cost-based prioritization of trading partners ω_n or even cross off the list of trading partners some agents. Visually such behavior will not be such straightforward as in figure 3-3, however the number and value of trades could change.

2. How does the presence of energy storage systems impact the operation of P2P markets?
   The presence of energy storage systems influences the map of trades. They compete with the loads to be charged at certain moments, providing additional generation at the peak of demand. Within the consumer-centric P2P market with user preferences, one needs to control that the storage behaviour does not ruin the user preferences. In some cases, for this purpose, there could be proposed additional market rules and market reformulations. Besides that, developing the design of the P2P market with storage units, it is required to define the regulations related to the arbitraging.

   The impact of energy storage integration highly depends on the way we introduce storage: applied rules, ownership of storage systems, requests from the regulator and market participants etc. More generally speaking it can influence the P2P market in several ways:

   1. <u>Increase flexibility:</u> Energy storage systems enable the storage of excess energy generated from renewable sources during times of high production. This stored energy can be later utilized during periods of high demand or low production, providing flexibility to balance supply and demand in P2P energy trading.
   2. <u>Enhance grid stability:</u> Energy storage systems help improve grid stability by providing backup power during grid outages or fluctuations in renewable energy generation. This can enhance the reliability of P2P energy transactions and reduce the risk of disruptions due to intermittent energy sources.
   3. <u>Through arbitrage:</u> Energy storage systems create opportunities for arbitrage in P2P energy markets by buying electricity when prices are low and selling it when prices are high. This can help maximize the economic benefits for market participants and contribute to a more efficient allocation of energy resources.
   4. <u>Through facilitation of integration of renewable energy sources and opportunity to participate in demand response initiatives.</u>

3. Why is managing uncertainty important in P2P energy markets, especially with renewable energy sources?
   Thank you for the comment. Managing uncertainty is critically important to ensure secure and stable operation of the market.
   Renewable energy sources are intermittent by nature, meaning their generation fluctuates based on weather conditions. This unpredictability can lead to supply-demand mismatches in P2P energy trading, making it essential to manage uncertainty to ensure a reliable energy supply. Uncertainty addressing approaches could help to find cost effective market solutions with the minimal cost of redispatch, and high probability that the system constraints are satisfied in case of deviations.

   Additionally, the production of renewable energy can vary not only in the short term due to weather changes but also in the long term due to seasonal and environmental factors. From this perspective, managing uncertainty is vital to account for these fluctuations and adjust energy trading strategies accordingly.

4. How does the stability of the P2P market get affected by energy storage systems and agent preferences, and how may market reformulations help with these issues?
   We appreciate the comment. The stability of the P2P market can be influenced by the presence of energy storage systems and diverse preferences of market agents.

   - Supply-demand balancing: Energy storage systems can help balance supply and demand fluctuations in a P2P market by storing excess energy and discharging it when needed. However, improper management or suboptimal operation of storage systems can lead to imbalances, affecting market stability.
   - Integrating Renewable Energy: Energy storage enables the integration of renewable energy sources, which can introduce variability and uncertainty in energy generation. Failure to adequately account for these factors can impact market stability by affecting price signals and grid reliability.
   - Within the consumer-centric P2P market with user preferences, one needs to control that the storage behaviour does not ruin the user preferences.
   - Market agents in a P2P market may have varying preferences, objectives, and risk tolerances when it comes to energy trading. These diverse behaviors can lead to market inefficiencies, price volatility, and potentially destabilize the market if not properly managed.

   Market reformulations and in particular clear rules for energy trading, arbitraging, interaction with DSO and other agents, correct design of incentive structures that align agent behaviours with market objectives can foster stability and sustainability in P2P markets.

Prof. Henni Ouerdane

The summary of issues to be addressed before/during the thesis defense
Overall, the work is sound and the thesis well-written. I have no particular concern nor objection to express.
However, I suggest to address the following points:

1. A suggestion for a more specific title can be: “Peer-to-peer energy market design and operation: from conceptual representation to real-life market requirements”. This is only a suggestion; other options are obviously possible, but the PhD thesis title should not contain elements that make it too vague.
   We appreciate the comment. We took into account the reviewer's feedback and revised the title of the thesis. We arrived at the following formulation of the title «Peer-to-peer energy market design and operation: a constrained optimization perspective»

2. In the publication list, separate the articles that report the doctoral research work from articles that contain contributions that are not directly related to the thesis. Manuscripts that are not yet accepted for publication, should be listed apart.
   Thank you for pointing this out. We updated the list of publication in the suggested way.

3. Update the publication information and organize it in reversed chronological order.
   We appreciate the comment. We reorganized the list of publications in the proposed reversed chronological order.

4. A clear formulation of the research question(s) is missing in the Introduction chapter. Please try and formulate such a question.
   Thank you for the comment. We modified Introduction chapter and introduced more explicit formulation of the research question, and research hypothesis.
   Research question is formulated as follows:
   How can the development of peer-to-peer energy markets be optimized to effectively account for network constraints, renewable energy uncertainty, and energy storage systems, while ensuring compatibility among different market instruments and maintaining computational efficiency?

5. The main assumptions which support the theoretical approach are not clearly formulated. Please try and formulate the main assumptions with bullet points in the Introduction. We also need to better see in the Conclusion chapter if these assumptions have been validated or not considering the obtained results.
   We appreciate the comment. We introduced the research hypothesis and more detailed assumptions in the Introduction chapter of the thesis. Additionally, we extended the concluding chapter with the reasoning about the applicability of assumptions.

6. Question: how is your work perceived by stakeholders in the P2P markets sector? Do you have feedback on your work beyond academia?
   Thank you for the question. It is interesting to note that the interest in this research area and the decision to develop it arose as a result of participation in the Asia Blockchain Week: Blockchain2Energy conference, where there was direct interaction with stakeholders in the P2P markets sector, such as LO3 Energy, Power Ledger and others, and the problem of compliance with network restrictions and moving away from conservative approaches was formulated. A lack of an analytical base for more advanced implementation of pilot markets was also identified. Although at the moment we were focused on studying optimal approaches to solving this problem, conceptual development and creation of corresponding distributed procedures, interest was shown by representatives of Energynet. Now we agreed to keep our finger on the pulse.

Prof. Alexander Nazin
Remarks
Following points may help in improving the thesis:

1. Provide discussion about alternative approaches to ADMM.
   We appreciate the comment. Optimization techniques that could be applied to develop distributed P2P market design can be divided into two branches. The first set of distributed optimization techniques is based on augmented Lagrangian decomposition. It includes Dual Decomposition, the Alternating Direction Method of Multipliers (ADMM), Analytical Target Cascading, and the Auxiliary Problem Principle. The second set of techniques is based on decentralized solution of the Karush-Kuhn-Tucker (KKT) conditions, and covers Optimality Condition Decomposition and Consensus+Innovation methods [1-4]. Application of the particular method highly depends on problem architecture and parameter tuning approaches. Choosing method we are finding balance between computational effort per iteration and amount of data exchange per iteration. Consensus ADMM is a recognized approach in energy systems with proved convergence properties [5]. It was initially designed as a robust method for arbitrary–scale optimization and distributed optimization. Although there are the drawbacks of the method in particular the iterations converge quickly to moderate accuracy but can be slow to converge to high accuracy, the convergence rate depends on ro, etc. today the method is applied to tasks from unit commitment to energy storage management. The analysis of the convergence rate and behaviour of the algorithm from [2] suggests the applicability of the approach for P2P trading that has been confirmed by practice in the current research. At the same time, we define the study of alternative approaches for distributed P2P market as a direction for further research.

   [1] D. K. Molzahn *et al.*, "A Survey of Distributed Optimization and Control Algorithms for Electric Power Systems," in *IEEE Transactions on Smart Grid*, vol. 8, no. 6, pp. 2941-2962, Nov. 2017, doi:10.1109/TSG.2017.2720471.
   [2] A. Kargarian *et al.*, "Toward distributed/decentralized DC optimal power flow implementation in future electric power systems," *IEEE Trans. Smart Grid*
   [3] B. H. Kim and R. Baldick, "A comparison of distributed optimal power flow algorithms," *IEEE Trans. Power Syst.*, vol. 15, no. 2, pp. 599–604 May 2000.
   [4] A. J. Conejo, E. Castillo, R. Minguez, and R. Garcia-Bertrand, Decomposition Techniques in Mathematical Programming. SpringerVerlag Berlin Heidelberg, 2006.
   [5] S. Boyd, N. Parikh, E. Chu, B. Peleato, and J. Eckstein, "Distributed optimization and statistical learning via the alternating direction method of multipliers," Found. Trends Mach. Learn., vol. 3, no. 1, pp. 1–122, 2011.

2. Provide discussion about accounting losses in peer-to-peer trading
   We appreciate the comment. Losses in peer-to-peer trading can occur due to various factors such as technical inefficiencies, distribution losses, fraud, and market inefficiencies. In our analysis, we make an assumption that the lines are lossless and apply corresponding network models. If we relax this assumption, one can apply the loss allocation approaches proposed in [1] and [2] based on loss adjustment process or loss sensitivity factors that fits well into our methodology. In the current formulation, similarly to the trade-independent network fees, there could be proposed trade-independent slack-bus payments aiming to compensate losses; however, this approach cannot be considered as the fair allocation of losses.

   [1] Felix F. Wu, Pravin Varaiya, Coordinated multilateral trades for electric power networks: theory and implementation, International Journal of Electrical Power & Energy Systems, Volume 21, Issue 2, 1999, Pages 75-102, ISSN 0142-0615,
   https://doi.org/10.1016/S0142-0615(98)00031-3.
   [2] J. Guerrero, A. C. Chapman, and G. Verbiˇc, "Decentralized P2P energy trading under network constraints in a low-voltage network," IEEE Transactions on Smart Grid, vol. 10, no. 5, pp. 5163–5173, 2019.

3. Extend description of further directions of research in the field.
   Thank you for the comment. We have extended the directions of further research work highlighting the concerns related to private, and cyber secure operation of the market and the development towards approaches that can help to lighter computation and increase algorithmic flexibility, including sparsification.

4. Provide references to the existing pilots of peer-to-peer trading.
   We appreciate the comment, and have extended the list of pilot projects (Brooklyn Microgrid, Powerpeers, Verv, Power Ledger, Wien Energie, LO3 Energy, FlexiDAO, etc.), as well as add the corresponding links.
   These pilot projects showcase the growing interest and innovation in peer-to-peer energy trading globally, demonstrating the potential for decentralized energy markets to transform the way we produce, consume, and trade energy.

Prof. Marina Dolmatova

Remark for improving the thesis:

While the thesis is a strong and well-structured body of work, there are a few areas that could be further clarified or expanded upon:

1. Scalability of Proposed Algorithms: Given the complexity of P2P trading algorithms, a more detailed discussion on scalability, particularly in large-scale applications, would strengthen the thesis. Addressing the computational feasibility of the proposed algorithms in larger grids or urban settings with thousands of participants would be insightful.

We appreciate the comment. There are several aspects to consider in relation to this question:

- Scalability of distributed approaches vs. scalability of centralized approaches
- Scalability of the particular algorithm and chosen methods
- Scalability requirements from market perspective

We would like to discuss the raised points one by one.

With increasing penetrations of distributed energy resources, the centralized paradigm most prevalent in current power systems will potentially be augmented with distributed optimization algorithms. Rather than collecting all problem parameters and performing a central calculation, distributed algorithms are computed by many agents that obtain certain problem parameters via communication with a limited set of neighbours. Depending on the specifics of the distributed algorithm and the application of interest, these agents may represent individual buses or large portions of a power system. This direction is attracting attention not only in energy systems. Distributed algorithms find its practical application in unmanned vehicles, drones and in other areas.

<u>Scalability of distributed approaches vs. scalability of centralized approaches</u>

Distributed algorithms have several potential advantages over centralized approaches. The computing agents only have to share limited amounts of information with a subset of the other agents. This can improve cybersecurity and reduce the expense of the necessary communication infrastructure. Distributed algorithms also have advantages in robustness with respect to failure of individual agents (no single point of failure problem). Further, with the ability to perform parallel computations, distributed algorithms have the potential to be computationally superior to centralized algorithms, both in terms of solution speed and the maximum problem size that can be addressed. Finally, distributed algorithms also have the potential to respect privacy of data, measurements, cost functions, and constraints, which becomes increasingly important in a distributed generation scenario. Summing up, the possibility of parallel computations makes distributed approaches scalable.

Scalability of the particular algorithm and chosen methods

ADMM demonstrated its efficiency for the solution of convex optimization problems in a distributed manner. In our analysis we simulate benchmark test system with 39 buses and 46 lines. We run the simulation setup in MATLAB on personal computer (Intel Core i5-7200U CPU, 2.50 GHz, RAM 8 GB, 64-bit Operating System). Not considering parallelization (individual agents' tasks are solved sequentially on one computer), algorithm (3.10) converges with the primal and dual tolerances 10^{-5} and power flow tolerance 10^{-3} in 59 sec. In this way, considering parallelization, it takes around 2 sec for the market to be cleared, which is adequate for the P2P market and has potential for scaling. Optimization of individual problems was done using built-in MATLAB function quadprog.

At the same time, we highly agree with the raised point and acknowledge that the main challenges towards real world implementation of distributed P2P market designs entail scalability and asynchronicity of the negotiation process.

The article [1] contains the comprehensive computational analysis of 3 architectures: distributed community-based market approach, distributed and decentralized peer-to-peer electricity markets. As expected the analysis of convergence, scaling properties, and resilience to delays demonstrate that the community-based approach faster and more robust. It means that the introduction of the individual trades of agents with other agents p_{nm} (n) which gives opportunity of product differentiation makes the algorithm more complex and less scalable by itself in a sense, regardless of the specific algorithm used. It applies to our algorithm too.

However, the P2P market is the only framework allowing for product differentiation. It is has been identified that the communication matrix sparsity, i.e. the number of possible trading partners, is a possible way to decrease the algorithm complexity and instability. Several extensions and convergence rate improvements including the sparsification has been discussed in *3.1.6 Discussion*.

Scalability requirements from market perspective

As we discussed in section *Discussion: Real-time P2P Market* the original concept of the P2P market was discussed in relation to the whole distribution system. Today the scientific thought is evolving towards the modified versions of the P2P market:

- P2P trading within the zones (parts of distribution system, microgrids): transmission tariff, absence of the economy of scale, and similar nature of the agents make the trading with the distant part of the distribution system financially unattractive and highly unlikely;
- Hybrid version of the P2P market;
- P2P trading within and between the microgrids, VPP, etc.,

These approaches state lower scalability requirements (number of participants) for the P2P market and for the ICT infrastructure.

Summary

Summing up the question of scalability and asynchronicity is challenging for the P2P market. Based on the reasoning above we expect the P2P market to be a part of hybrid nested architectures where the scalability requirements for P2P trading will be limited to hundred/hundreds of agents but not thousands. In this way, from this perspective the proposed approach is applicable for P2P trading, at the same time we define the study of alternative approaches for distributed P2P market with lighter computation and higher algorithmic flexibility as well as investigation of sparsification mechanisms as a direction for further research. Another direction of research is an investigation of the potential of combinatorial auction [2] which recently has shown good scalability properties in the studies.

[1] F. Moret, T. Baroche, E. Sorin and P. Pinson, "Negotiation Algorithms for Peer-to-Peer Electricity Markets: Computational Properties," *2018 Power Systems Computation Conference (PSCC)*, Dublin, Ireland, 2018, pp. 1-7, doi: 10.23919/PSCC.2018.8442914.
[2] G. Tsaousoglou, P. Pinson and N. G. Paterakis, "Transactive Energy for Flexible Prosumers Using Algorithmic Game Theory," in *IEEE Transactions on Sustainable Energy*, vol. 12, no. 3, pp. 1571-1581, July 2021, doi: 10.1109/TSTE.2021.3055764.

The corresponding paragraph has been extended in the thesis.

2. Consumer Preference Impact: The candidate might expand upon how consumer preferences (e.g., proximity to suppliers or carbon footprint considerations) affect overall grid efficiency and welfare. An analysis of potential trade-offs between individual preferences and grid optimization goals could be valuable.

   We appreciate the comment. The proposed designs of the P2P market work in an endogenous manner. It results in the nodal prices, encompassing both generation related and congestion-related costs. At the same time we observe that traditional tariff for the end-users encompasses several extra fees. To ensure the cost recovery of the network we introduce β_n^0 in the objective function of the optimization problem. In general case, β_n^0 is the sum of the individual terms responsible for certain additional payments. Through this term the overall grid efficiency and welfare are ensured. Individual preferences are entered through coefficients β_{nm}. The coefficient β_n^0 could be universal for all agents or could be trade-dependent, in particular, reflect the electrical distance between the agents and stimulate the trading between the neighboring agents and not encourage trades between very distant agents.
   Indeed, in this sense there could be a tradeoff between individual preferences and grid optimization goals, for example, if we want to trade with the "green" generator very distant from us. In this case the final decision about the trading partners and trades itself is made based on the ratio of the resulting cost functions of agents accounting for all type of coefficients. Depending on the concrete form of the coefficients, it might occur that the additional cost assigned to the agents with high level of emissions is such high that from the perspective of the maximum welfare of the P2P market (our objective function) it might be financially attractive to trade with the distant "green" agent.

Prof. Yanli Liu

1) Further Validation of Models: While the proposed models and algorithms are well-supported by simulations, additional validation using real-world data would strengthen the credibility of the results.
   We appreciate the comment and agree that it would be interesting to apply the proposed algorithms on real-world data. We foresee that for this purpose it is required to find an existing pilot-project partner and not the part of distribution system by now due to the problem setup: the simultaneous presence of advanced communication infrastructure and overloads, and the necessity to introduce agents' cost functions.
   In our simulations, we use IEEE test case benchmark models, widely used in the literature. It is important to note that we do not expect the principal changes in the behavior of the proposed procedures as they account for behavioral patterns of agents and existing physics.

We expect a large amount of work related to code refactoring and optimization, its adaptation for not pure radial networks or hybrid models, development heuristics for algorithm parameter tuning, and adaptation of the algorithm for the level of smartness of end-user devices, and consider this as a future research work

2) Discussion of Scalability: The dissertation could benefit from a more detailed discussion on the scalability of the proposed methodologies, particularly for larger and more complex networks.
We appreciate the question. As the question is apt and relevant the similar comment is appeared in the set of comments of Professor Marina Dolmatova. Please see the full answer to your question in the section of answers to comments of Professor Marina Dolmatova.

3) Economic Impact Analysis: A more comprehensive analysis of the economic impacts of the proposed P2P market designs, including long-term financial sustainability and cost-benefit analysis, would provide valuable insights.
Thank you for the comment. Long-term financial sustainability for P2P market refers to the ability of the market to maintain economic viability, attract investments, and ensure continued operational efficiency over an extended period. A sustainable P2P market should be able to generate sufficient revenue to cover operational expenses, infrastructure costs, and provide adequate returns on investments for market participants, in our case be at least more financially attractive than selling electricity to the guaranteeing supplier (C1).
The P2P market will be financially sustainable if we introduce network fees depending on the scenario covering one or all tariff components except of cost of electricity production: transmission tariff - 55% of the tariff in Russia, sales markup of the guaranteed supplier 4,9%, infrastructural payments 0.1%, and if the long term P2P trading will be more financially attractive for agents than conservative approaches. If the network fees would be too harsh it could kill the financial sustainability of the P2P market. We see the opportunities for decreasing the network fees introduced in the market in exchange for the opportunity for the network to get ancillary services provision or demand response services if the P2P market could operate in a hybrid mode. Additionally, economic viability of P2P market designs is increasing in the cases of high electricity tariff, as well as in the case of the isolated microgrids.

The introduction of network fees is critically important for the industry. One can foresee that the number of consumers connected to the utility companies will decrease with the growth of the alternative approaches to the supply. It threatens the foundation of the cost recovering strategy for such companies. Reduced number of consumers will lead to the increased price of supply services and the following increase in the number of disconnected or preferring alternative supply mechanism agents. The industry will face a death spiral. The network fees and other instruments are required to ensure cost recovery for all market participants and enabling agents.

4) Comparative Study with Other Market Designs: Although the dissertation compares the proposed methods with correction-based algorithms, a more extensive comparative study with other market designs (e.g., centralized markets, virtual power plants) would enhance the understanding of the relative advantages and disadvantages.
We appreciate your comment however it seems that such analysis was overlooked in such a long thesis in the Introduction chapter where we compare three principal prosumer-market models (figure 1-2).

5) Addressing Security and Privacy Concerns: Given the increasing importance of security and privacy in P2P energy markets, a dedicated section discussing these concerns and potential solutions would be beneficial.

Addressing security and privacy concerns in P2P energy markets is crucial to ensure the trust and integrity of the market ecosystem. During the iterative process of information exchange the leakage of data privacy still may arise. To address this problem privacy preserving modifications of the algorithm could be proposed. Authors in [1] propose an algorithm where each agent approximately solves a perturbed optimization problem that is formulated from its local private data in an iteration, and then perturbs the approximate solution with Gaussian noise to provide the distributed privacy guarantee. In [2] the methods of dual variable perturbation and primal variable perturbation to provide dynamic differential privacy are proposed. Another approach to address the problems of privacy, trust, and resilience is suggested in [3]. In this work authors combine a smart-contract based validator with an external optimizer to clear the market.

Integration of multiple new agents as prosumers, DERs, electric vehicles and others, without reference to market architectures, raises additional question of insuring high level of cybersecurity. A survey of IoT-enabled cyberattacks with the assessment of attacks' paths, security issues as well as mitigation strategies can be found in [4] and [5].

In particular, the types of attacks in IoT are summarized in the form of scheme below [4].

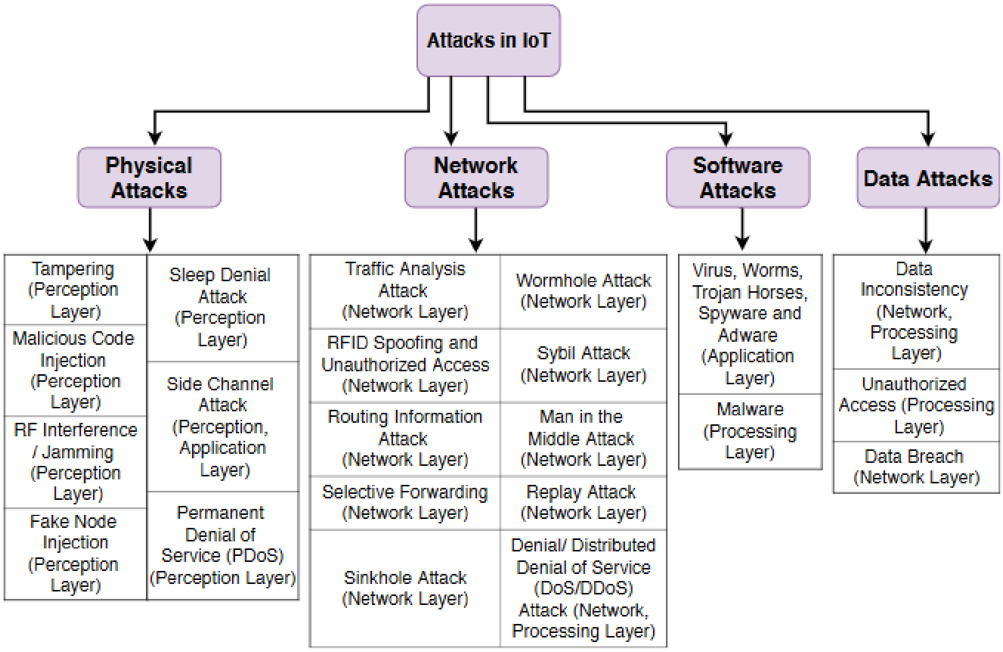

Figure 2: *Attacks in IoT*

Each type of the attack assumes its own mitigation strategy.

In a more general sense, the following approaches can be distinguished:

- Encryption and Data Protection: Implementing strong encryption techniques and data protection measures can safeguard sensitive information shared among participants in P2P energy transactions. This includes ensuring end-to-end encryption of communications and secure storage of data.

- Identity Management: Employing robust identity management systems can authenticate the identities of participants in P2P energy markets, preventing unauthorized access and ensuring that only verified users can engage in trading activities.
- Cybersecurity Measures: Implementing cybersecurity measures such as firewalls, intrusion detection systems, and regular security audits can help protect the P2P energy market platform from cyber threats and attacks.
- Privacy-preserving Technologies: Leveraging privacy-preserving technologies like differential privacy and homomorphic encryption can help protect the privacy of participants' data while still allowing for meaningful analysis and transactions to take place.
- Regulatory Compliance: Adhering to relevant data protection regulations and industry standards can help ensure that security and privacy practices in P2P energy markets are in line with legal requirements, fostering trust among participants.
- User Education and Awareness: Promoting user education and awareness about security best practices, data privacy risks, and how to securely interact with the P2P energy market platform can empower participants to take active roles in protecting their information.

By incorporating these solutions, P2P energy market operators can enhance security and privacy protections, ultimately fostering trust among participants and enabling the continued growth and adoption of distributed energy trading platforms.

[1] Jiahao Ding, Jingyi Wang, Guannan Liang, Jinbo Bi, and Miao Pan. 2020. Towards Plausible Differentially Private ADMM Based Distributed Machine Learning. In Proceedings of the 29th ACM International Conference on Information & Knowledge Management (CIKM '20). Association for Computing Machinery, New York, NY, USA, 285–294. https://doi.org/10.1145/3340531.3411860
[2]T. Zhang and Q. Zhu, "Dynamic Differential Privacy for ADMM-Based Distributed Classification Learning," in *IEEE Transactions on Information Forensics and Security*, vol. 12, no. 1, pp. 172-187, Jan. 2017, doi: 10.1109/TIFS.2016.2607691.
[3]A. Laszka, S. Eisele, A. Dubey, G. Karsai and K. Kvaternik, "TRANSAX: A Blockchain-Based Decentralized Forward-Trading Energy Exchanged for Transactive Microgrids," *2018 IEEE 24th International Conference on Parallel and Distributed Systems (ICPADS)*, Singapore, 2018, pp. 918-927, doi: 10.1109/PADSW.2018.8645001.
[4] I. Stellios, P. Kotzanikolaou, M. Psarakis, C. Alcaraz and J. Lopez, "A Survey of IoT-Enabled Cyberattacks: Assessing Attack Paths to Critical Infrastructures and Services," in *IEEE Communications Surveys & Tutorials*, vol. 20, no. 4, pp. 3453-3495, Fourthquarter 2018, doi: 10.1109/COMST.2018.2855563.
[5] Jayasree Sengupta, Sushmita Ruj, Sipra Das Bit,
A Comprehensive Survey on Attacks, Security Issues and Blockchain Solutions for IoT and IIoT,
Journal of Network and Computer Applications, Volume 149, 2020, 102481, ISSN 1084-8045,
https://doi.org/10.1016/j.jnca.2019.102481.