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PAPER

Energy-Efficient Green Information Centric Networking for Future Wireless Communications

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ABSTRACT

Energy-efficient green information-centric networking (EEGICN) is proposed in this paper for advancing future wireless communication networks by addressing the challenge of energy consumption. This model can adapt the power consumption of network nodes to optimized values according to the associated link utilization. The model aimed to reduce energy consumption and increase network performance and stability. The EEGICN model incorporates efficient routing mechanisms, content caching strategies, and energy-intelligent communication protocols to improve resource utilization across the network infrastructure. EEGICN minimizes large data transmission, reduces power consumption, and reduces network congestion. Popular resources are cached in key network locations, and proximity data is exchanged to achieve this. The model also includes dynamic power management algorithms that adapt to changing traffic demand and network conditions to provide consistent performance across a variety of operational scenarios. In comparison to current wireless network systems that employ various forms of cache, the evaluation findings demonstrated that EEGICN can increase network efficiency by dramatically lowering the number of hops and energy consumption. Future networks may find this application to be a quick and easy way to transmit content.

KEYWORDS

information-centric networking (ICN), future wireless communications, energy efficiency (EE), wireless network, green information-centric networking

1 INTRODUCTION

Information-centric networking (ICN), which moves the networking focus from host locations to transmitted information, is an impressive contender for future network architecture [1, 2]. In contrast to the existing host-centric Internet, ICN minimizes reaction time, traffic load, and network source consumption because requested content data can be received from a replica rather than the lone content source, as in the IP-based Internet architecture [3]. Even if ICN helps consumers and

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network operators, there are still issues with the ICN architecture, including caching and routing as well as issues with flooding, particularly with power consumption. Therefore, it is imperative to search for energy efficiency (EE) models in ICNs, especially as the demand for ICNs increases and energy consumption rises due to economic and environmental concerns.

Information-centric networking is considered a promising global-scale future internet (FI) design; nevertheless, because of the additional power needed for content router caching, its in-network caching capabilities create issues with EE [4]. In addition, current Internet architectures are too large to anticipate large volumes of traffic or, in the worst case, due to the large amount of energy wasted due to the lack of use of equipment and network connections.

Energy efficiency has received little attention in ICN, particularly when it comes to working in wireless environments, despite the fact that it is a major consideration in the strategy of wireless communications for the future network [5]. However, the combination of ICN and green network for wireless access networks has not been properly researched. EE concerns are increasingly complex due to rising energy prices, the rapid expansion of the number of users in broadband wireless networks, and the rising demand of users for content in future networks. This problem underscores the necessity of ICN-based wireless platforms that are energy-efficient for upcoming communications [6].

To facilitate the deployment of wireless access networks in the future, we have developed an ICN model called energy-efficient green information centric networking model (EEGICN) that can deliver content in an extremely energy-efficient manner while maintaining high network performance. With the assumption that network devices are power-aware and able to adjust their control based on connection speed, EEGICN employs an adaptive performance strategy for content providers and content components in order to lower system power consumption across the network. Additionally, to minimize the number of hops in wireless local area networks (WLANs), EEGICN employs a hybrid caching approach as opposed to the standard ICN caching technique.

Hence, the goal of this study proposal is to create a dynamic, energy-efficient ICN model for the Internet of the future by adjusting router link utilization based on content popularity and server optimal operating mode to maximize network energy consumption value.

The remainder of the paper is arranged as follows: Section 2 presents related research. The energy-efficient green ICN model is explained in Section 3. Section 4 presents the simulation results, discussion, and mathematical model for energy consumption evaluation. Finally, we conclude with Section 5.

2 LITERATURE REVIEW

[7] proposed ideal ICN architecture with the capacity to adjust power consumption based on server interest traffic to maximize server or content provider processing power to address over-provisioning network systems. The simulation results in SIM prove the efficiency of their scheme in terms of power consumption compared to both conventional ICN and IP-based networks. With appropriate hardware support, their model can offer substantial savings for the future Internet but the scalability needs to be expanded.

[8] suggested a collaborative energy-efficient routing protocol (CEERP) model in 5G wireless sensor networks for viable communication. In order to enhance the

model performance, they used an enhanced multi-objective seagull algorithm as an optimization system. Throughput, consumption of energy, data pack transmission, network period, speed, and routing overhead are used as the performance metrics. This system consumes less energy while enhancing network lifetime and EE compared to the existing protocols.

Cooperative communication is proposed by [9] to extend the lifespan of the community by having sensor nodes balance their electricity usage and enhancing community safety by using the most reliable relay node to transmit data. Their model reduces the strength consumption of character nodes by having nearby sensor nodes work together to communicate records to a base station.

[10] presented a novel approach called lightweight satellite-borne terahertz communication space information-centric network (LSICN) that provides high-speed, high-capacity communication in networking by using the transmission benefits of the information-centric network. It also provides an overview of important techniques that address the difficulties raised.

[11] suggested an efficient forwarding technique to improve energy management in wireless ICNs with energy constraints. To do this, the network context, internal energy, and device categorization are taken into account. Their suggested approach makes use of the neighborhoods' awareness of when to listen and forward packets to continuously handle mobility and enhance the delivery of content.

3 METHODOLOGY

The proposed EEGICN model aims to enhance network efficiency and sustainability by leveraging ICN principles, energy efficient technologies, and renewable energy sources. The proposed EEGICN model is depicted in Figure 1. Consumer electronics, including laptops, tablets, smartphones, and Internet of Things devices, are at the top of the model. The majority of network resources, applications, and content consumption are consumed by these devices. At ICN, content takes precedence over space. This means that instead of requesting data from a specific server, users request it by name and content identification. These modifications allow for improved caching and data streaming techniques while reducing the size of data transfers.

The first point of connection between user devices and the public network is the access network layer [12]. Among them are: Wi-Fi hotspots: These gadgets offer wireless internet access in public places, offices, and residences. In order to provide low-power, fast Internet connectivity, Wi-Fi hotspots are necessary. Mobile towers: Provide users with an on-the-go connection by distributing access to the mobile network. In order to better control energy usage, mobile phone towers must employ technologies such as tiny cells and alternate networks to maximize EE. Side Nodes: These are crucial to the ICN because they bring processing and caching closer to the users. These nodes lower latency and save energy by minimizing the amount of data that needs to be sent across the network by caching requested content at the edge.

The ICN's backbone is the fundamental network layer, which is made up of highly capable switches and routers that manage a lot of data routing and forwarding. At this level are switches and routers: These gadgets control network-wide data transmission. Switches and routers in an energy-efficient ICN are built to use the least amount of electricity possible without sacrificing functionality. Content-routing systems (caching): These routers may store a lot of stuff in their caches. By storing data closer to the location of requests, content routers lessen the strain on the network core and the effort required for data transit.

Router with EE: This gadget is designed to consume less energy. Network power reductions can be achieved through the use of technologies such as power optimization, which enables routers to adjust power usage based on current loads and employ energy-efficient hardware components.

The infrastructure and servers of the data center layer store and handle user-requested content. The principal elements are:

- Provider of Content (Server): Users can access programs and content hosted on this server. These servers at ICN are mobile-optimized, have effective cooling systems, and maximize energy savings through virtualization.
- Sources of renewable energy: Data centers are employing renewable energy sources such as solar and wind turbines more often in an effort to lower their carbon emissions. By using renewable energy, data centers can have sustainable electricity, become less reliant on fossil fuels, and emit fewer greenhouse gases.

The current ICN power consumption represents the case where there is no green system connected to the ICN system, and its power consumption is as follows:

$$\begin{aligned} E_{ICN} &= \eta E_{c-ICN} + DE_s \\ &= \eta\left(\rho_{R1-ICN} T_w + \rho_{R3-ICN} T_w\right) + \eta_1 \rho_{R2-ICN} T_w + \eta_2 \rho_{R2-ICN,AP} T_w + DE_s) \end{aligned} \tag{1}$$

Where, ρ_{R1-ICN}, ρ_{R2-ICN}, and ρ_{R3-ICN} represents embodied power, working power and cache memory power of a CN, correspondingly.

Energy consumption in an IP-based network system can be represented using the following term:

$$\begin{aligned} E_{IP} &= \eta E_{c-IP} + DE_s \\ &= \eta_1 \rho_{R1-IP} T_w + \eta_2 \rho_{R2,AP-IP} T_w + D\left(\rho_{E1} T_w + \rho_{E2} T_w + \rho_{E3} T_w\right) \end{aligned} \tag{2}$$

Where, E_{c-IP} and E_s are energy consumed by an IP router and server respectively. ρ_{R1-IP}, ρ_{R2-IP}, and $\rho_{R2,AP-IP}$ are the embodied power of a network node, working power of an IP router, and AP, respectively. η_1 and η_2 represents number of routers. ($\eta_1 + \eta_2 = \eta$). The working time of the entire system is represented as T_w.

Energy consumption in the suggested green ICN system is a grouping of two optimized value to reduce network system energy.

$$E_{ICN-Proposed} = \sum_{n=1}^{\eta} Optimized\, E_{c-ICN,r_n} + \sum_{m=1}^{D} Optimized\, E_{s-ICN,S_m} \tag{3}$$

To guarantee effective data routing, power management, and overall network performance, the management and control layer keeps an eye on every aspect of network operation. At this level are:

- Control server: This server oversees network functions, including traffic flow, resource allocation, and network security. This is crucial to implementing the ICN principles by directing data requests to the nearest or best source of information.
- Traffic management: By distributing the load and minimizing congestion, this system makes sure that data transfers across the network happen smoothly. Through data channel optimization, traffic management systems contribute to a decrease in the energy consumption of data transmission.

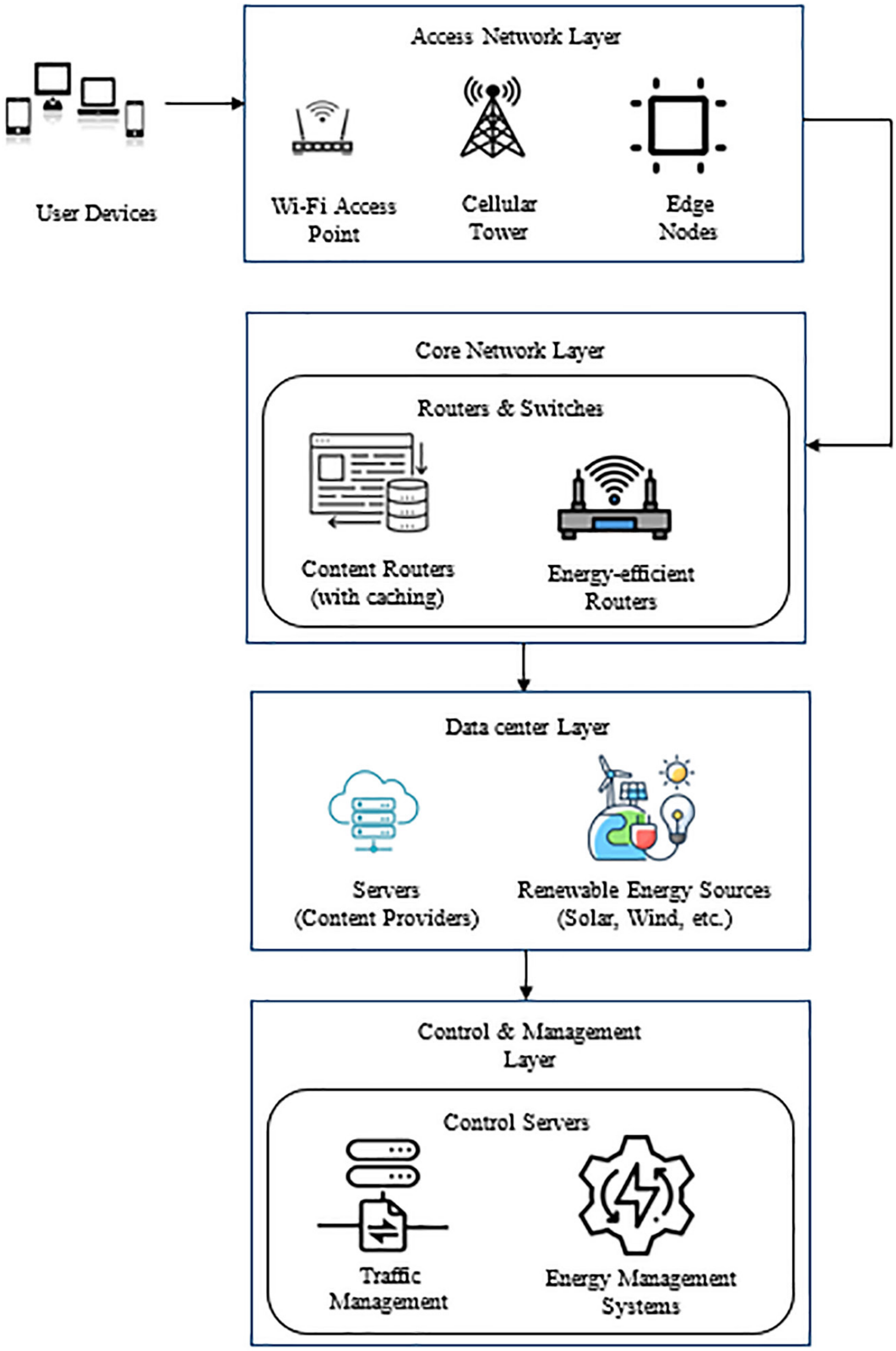

Fig. 1. Proposed energy-efficient green information-centric networking model

- Energy management system: This system keeps an eye on and maximizes power usage throughout the network. It can oversee the installation of renewable energy sources, apply energy-saving measures during periods of low activity, and modify the energy use of network components based on current demand.

4 RESULTS AND DISCUSSION

In this section, the benefits of the proposed EEGICN scheme are validated using SIM [13], an NDN simulator that can be used on NS-3. It uses the 802.11n standard for wireless access points (Aps). Each client node (CN) in the simulation is equipped with an NDN stack, which consists of three main functional blocks corresponding to the architecture of the NDN node: pending table music (PIT), forwarding information base (FIB), to track the content store. (CS). All network devices are assumed to support the adaptive link rate (ALR) feature (f = 1). Because the Wi-Fi Direct protocol uses MAC Layer 2 for wireless communication and NDN functionality at the network device level, this distinction does not affect the overall performance of the wireless access network or the system power model.

The following metrics are evaluated in the proposed simulation to assess the efficiency of CAGIM over the IP-based system and conventional ICN in terms of power consumption and network hop reduction ratio, taking into account that average power savings of a network system is total system energy over network runtime.

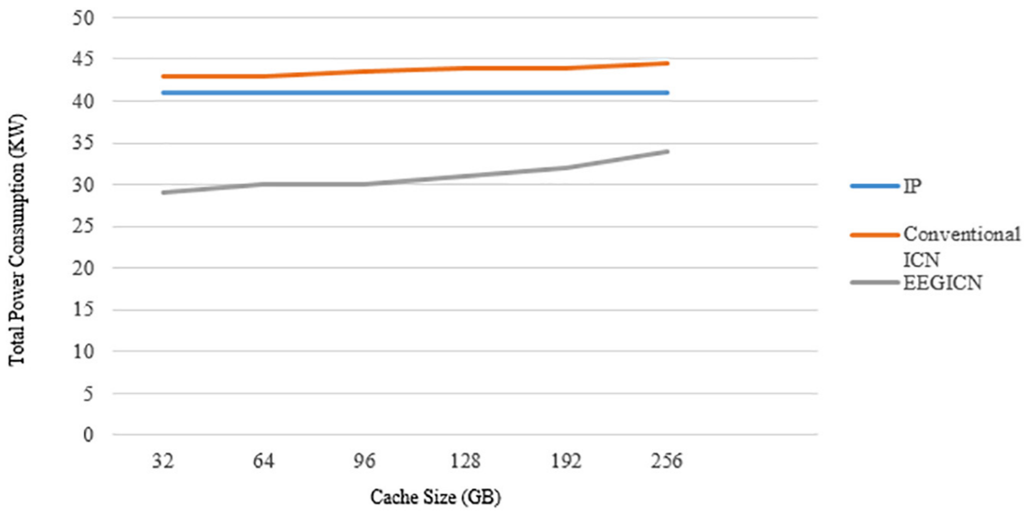

Fig. 2. Power consumption of network systems with various cache sizes

4.1 Effect of client node cache size on total power consumption of the network system

To illustrate the network scalability, we take into account seven possible candidate CN cache sizes (up to 256 GB). According to the simulation result exposed in Figure 2, the size of the CN cache affects the power consumption of ICN-based systems, while the power of IP-based networks is unaffected by the size of the cache since IP routers lack both a cache and a caching function. In specifics, when we increase the cache storage size of CNs, the power of both the conventional ICN and the suggested ICN increases since more power is needed for CN caching capability. Furthermore, when compared to alternative network architectures, the suggested approach can save a substantial amount of power consumption. For instance, the suggested energy-efficient Green ICN model, with 128 GB cache size CNs, can save roughly 10% and 13% of the electricity in the same situation when compared to the IP-based model and the standard ICN (NDN architecture), respectively.

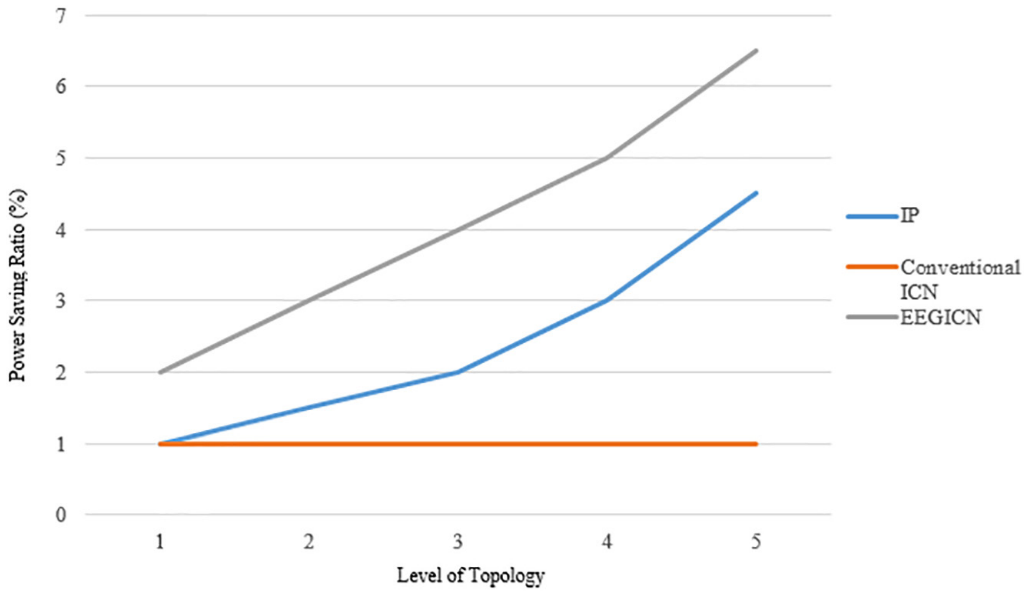

Fig. 3. Power saving ratio

4.2 Effect of power saving ratio of ICN CNs at different levels

This paper examines the power consumptions of 256 GB CNs with various ICN systems, including EEGICN, IP based networks, and conventional ICN, in order to demonstrate the impact of power saving of CNs at different levels of the proposed network topology. The comparison of these methods' power-saving ratios, as shown in Figure 3. Specifically, by employing an ALR-based approach, the EEGICN model outperforms the regular ICN and IP network in terms of EE of network devices. This is because, rather than utilizing LCE with LRU, CAGIM uses context-based naming, hybrid caching methods, and link rate optimization starting at the first level. Additionally, the outcome demonstrates that EEGICN is a scalable solution to ICN that scales well with network size since it functions more power-efficiently at higher network layers.

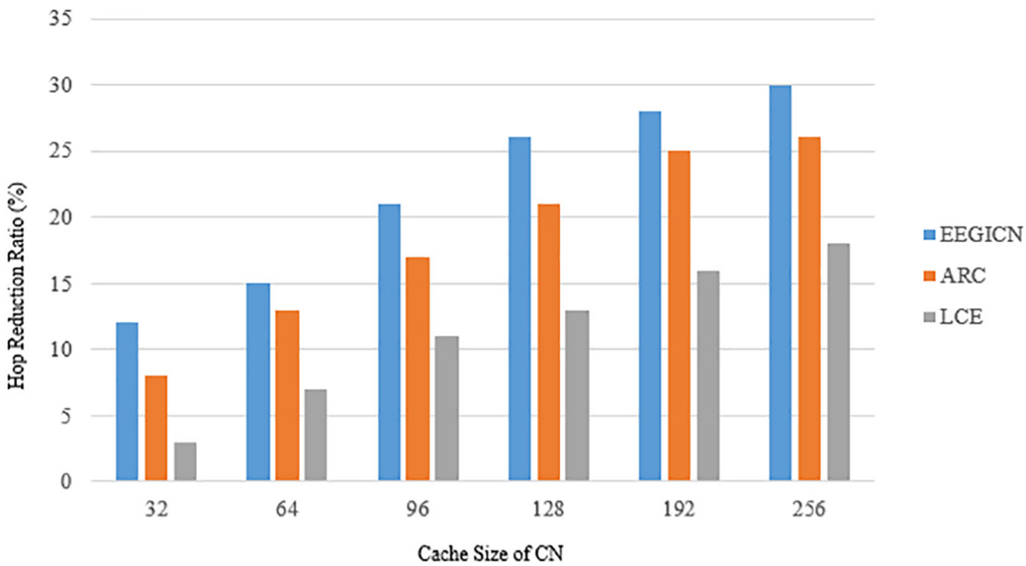

Fig. 4. Hop reduction ratio

4.3 Effect of hop reduction ratio on different caching configurations and sizes of the CN cache

In order to assess the suggested hybrid caching approach, we contrast EEGICN with the two most eminent caching techniques in ICN: For network systems having caches, ARC leverages multiple listed caches to get a good cache hit and LCE is the ICN default cache placement policy.

In terms of hop count for content retrieval, Figure 4 demonstrates that the suggested model performs best in terms of distance savings, while LCE performs worse because of its high cache redundancy. Furthermore, splitting the CN cache space results in better performance than the option of sharing the cache across all content categories without partitioning, as demonstrated by the great hop reduction ratios of EEGICN and ARC.

Overall, the evaluation outcomes show that the proposed EEGICN, when combined with energy-conscious network devices, can consistently outperform other current network systems that use various, pertinent, and widely-used caching schemes, thereby achieving the dual goals of well-organized content delivery and a high energy savings ratio in the network.

5 CONCLUSION

In this paper, the EEGICN model is introduced to solve the energy consumption problem of future wireless networks. By integrating efficient routing, intelligent content caching, and electronic communications protocols, EEGICN optimizes resource utilization and improves network performance and stability. Simulations using NDNSIM showed that EEGICN significantly reduces energy consumption and network degradation compared to IP-based ICN systems and standard ICN systems. This is achieved through robust power management, strategic caching of popular content, and efficient short-term data transfer. EEGICN's hybrid caching approach improves EE and network performance by reducing hops for content retrieval. The results demonstrate the potential of EEGICN as a scalable and sustainable solution for future networks, capable of adapting to different applications and processes and ensuring consistent performance. As energy costs rise and the need for reliable wireless communications increases, EEGICN offers a cost-effective way to develop green communications networks. This study will contribute to the development of a sustainable and efficient network infrastructure, paving the way for future research and implementation aimed at improving the lifetime and performance of wireless communication networks.

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