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Enhancing Reliability and Sustainability of Green Communication in Next-Generation Wireless Systems through Energy Harvesting

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Abstract: This research investigates strategies aimed at achieving reliable and environmentally sustainable Transmission in future-oriented wireless frameworks via the integration of energy harvesting technologies. As that demand for wireless connectivity continues to escalate, there is a pressing need to minimize environmental impact. Energy harvesting offers a promising solution by harnessing ambient Natural energy forms like solar, wind, and kinetic to energize wireless infrastructure and devices. The central goal of this investigation is to design robust communication protocols and network architectures specifically designed to operate efficiently on harvested energy. This encompasses the formulation of effective power management techniques, adaptive transmission strategies, and dependable error control mechanisms. These innovations are crucial for maintaining seamless connectivity, even amidst fluctuating energy availability. Methodologically, the research employs simulation models to Measure the performance of wireless networks incorporating energy-harvesting techniques across diverse practical scenarios. Key performance Measures like energy efficiency, reliability, latency, and throughput will be meticulously analyzed to assess the effectiveness of the proposed methodologies. The outcomes of this study are anticipated to significantly advance the field of sustainable wireless communication technologies. By leveraging energy harvesting technologies effectively, the research aims to contribute to the development of greener and more resilient next-generation wireless systems. These systems are poised to meet the burgeoning demands for connectivity while concurrently reducing the overall environmental footprint associated with traditional wireless communication infrastructures.

Keywords: Realiability; Sustainability; Green Computing; Wireless; Energy Harvesting.

1. Introduction

Energy harvesting enables wireless devices to collect ambient energy and convert it into useful electricity [1, 3]. The technology reduces the dependency on traditional energy sources and reduces the ecological impact of wireless networks. This project investigates the potential of data collection to facilitate green communication in the context of RF-based Wireless Sensor Networks (WSNs) and Internet of Things (IoT) devices. Wireless sensor networks often face performance and battery life issues [2], making energy harvesting solutions attractive to extend lifespan and reduce the need for battery replacement or recharging. Sensor nodes can use energy from various sources, such as solar energy, kinetic energy, thermal energy, and electromagnetic fields, to control communication modules. This approach not only extends the life of the wireless sensor network, but also supports continuous data monitoring and transmission to remote or hard-to-reach areas where oil can be controlled. The collection process requires the creation of complex algorithms and protocols. One of the main strategies involves the use of Q-learning algorithms, which dynamically optimize the energy collection and communication area based on environmental and operational variables [2]. The algorithms effectively control the transmission and forwarding to improve energy efficiency, network performance, and overall performance. The integration of energy consumption with Q-learning algorithms has major research and problems, such as energy saving design, power management strategy design, problem solving and problems, and maintaining effective communication in different electronic systems. Secure communication in future wireless communication has many benefits, including reducing dependence on traditional energy sources and reducing carbon footprint. In addition, energy harvesting can improve physical performance, facilitate long-term maintenance, and increase overall performance and reliability to extend the life of sensor nodes and IoT devices. It can support stable and reliable communication in advanced wireless systems. Wireless networks can achieve greater stability, efficiency, and repeatability by utilizing ambient energy and advanced algorithms. These research results are widely used in environmental protection, smart city, precision agriculture, industrial automation, medical care, and other industries, and lay the foundation for future planting and intersections.

2. Materials and Methods

The acronym "WSN" describes a system in which nodes are wirelessly connected to a central hub or base station (BS). The central station acts as the brain of the entire network, enabling communication with roaming users and other networks. The sensor node has four main components: a sensor unit for environmental data collection, a processing unit for data processing, a communication unit for data transfer, and a power supply unit, typically driven by chemical batteries. Add-ons will include mobility and behavior monitoring tools.

Energy Source → Energy Harvesting System →Energy Storage (s)→ Sensor Node

Table 1. Energy Harvesting Source Collection

Node	Solar Panel Power (mW)	Solar Panel Size (insin)	Energy Availability (mWh/day)	Storage Type	Battery Type	Battery Capacity (mAh)	Sensor Node Used	MPPT Usage
Heliomote	190	3.75 • 2.5	1140	Battery	NI-MH	1800	Mica2	No
Hydm Watch	276	2.3 • 2.3	139	Battery	NI-MH	2500	TelosB	Yes
Flecki	-	4.56 • 3.35	2100	Battery	N-MH	2500	NA	NO
Everlast	450	2.25 • 3.75	2700	Supercap (100F)	NA	NA	NA	Yes
Solar Biscuit	150	1 • 2	900	Supercap (IF)	NA	NA	NA	NO
Sunflower	4 PIN Photodiodes 20 mW	NA	100	Supercap (0.2F)	NA	NA	NA	NO
AmbiMax	400	3.75 • 2.5	1200	Supercap (two 22F) & Battery	Li-poly	200	TelosB	NO
Prometheus	130	3.23 • 1:45	780	Supercap (two 22F) & Battery	Li-poly	200	TelosB	NO

With a network of sensor nodes and base stations, WSNs enable the collection of data from multiple sources at the same time across large areas for applications such as fire detection, environmental monitoring, structural health monitoring, and healthcare. They find applications in home automation, asset tracking, visitor management, inventory control, agriculture, equipment fault diagnosis, environmental monitoring, surveillance, and military operations [7, 8].

The main goal of wireless sensor networks is to provide timely information by allocating sensors to applications that will operate in remote areas based on the analysis of the results. Considering that sensor nodes have less energy reserves (usually in remote or hard-to-reach places), it is important to optimize energy consumption and extend the operating life of electricity. The communication unit responsible for sending and receiving data is the largest for electronic applications [9].

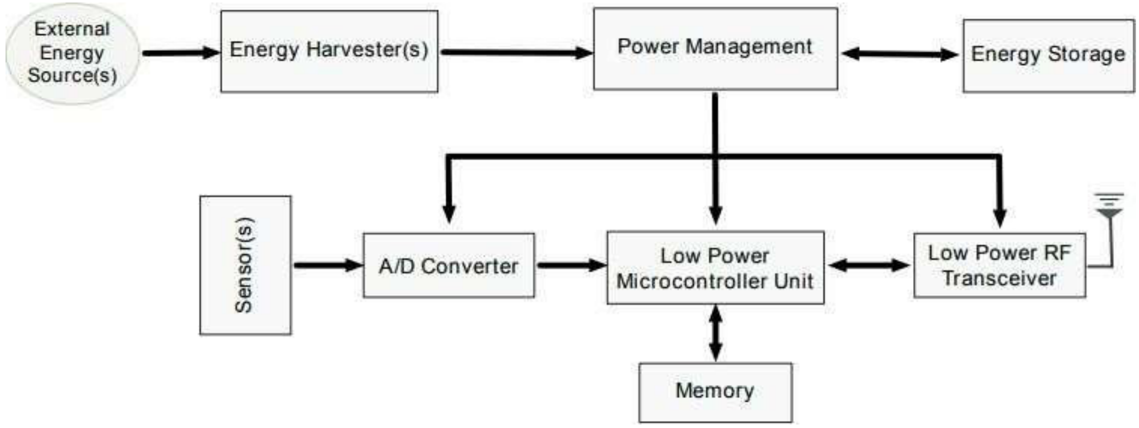

Figure 1. Energy-harvesting wireless node system design

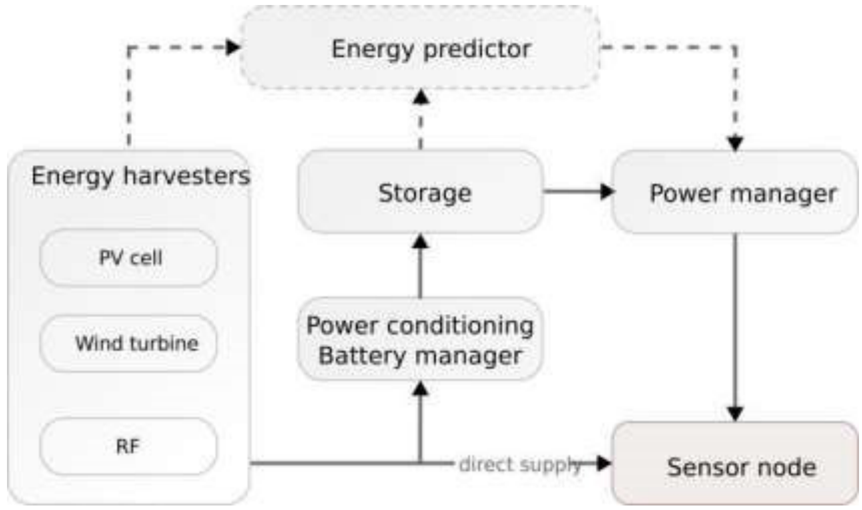

Figure 2. Depicts the overarching design for the power supply of a wireless sensor node that relies on energy harvesting.

2.1. Energy Harvesting

Energy harvesting refers to the process of capturing energy from natural sources such as solar energy, wind, vibration, sound waves, and heat [4]. The detected energy is converted into electrical energy that can be used to power wireless sensor nodes and devices [9]. Energy harvesting solves the problem of energy depletion, extending the life of nodes and improving network performance [10].

To improve the collection and conversion of ambient energy into electrical energy, electrical devices are placed in the network with additional nodes. For example, the efficiency of photovoltaic cells is directly proportional to their location, which determines how much sunlight they can convert into usable energy [12]. However, problems arise because electronic devices are usually larger than sensor nodes. To overcome this problem, additional power can be sent to the network and power supplies can be designed to provide efficient power distribution [15].

To change the Q value of the current state-function pair, use the following equation: Q(s,a)=Q(s,a)+α[R+β max¡ (Q(s− , a−))-Q(s,a)]Q(s,a) = Q(s,a) + \alpha \times \left[R + \gamma \times \max (Q) (s', a) ')) - Q(s, a)\right]Q(s,a)=Q(s,a)+αα[R+γαmax(Q(sα) ,aâ²))Q (s, a)] >Wireless Sensor Networks (WSNs) that use ambient power help reduce power consumption by operating continuously without the need for frequent battery replacement. The energy collected from sources such as solar panels or rechargeable batteries is stored continuously for future use. High-efficiency power management technology improves energy efficiency and extends the service life of the network. Integrating renewable energy into the network architecture helps effectively capture and convert ambient energy, maintaining efficiency and reliability over time.

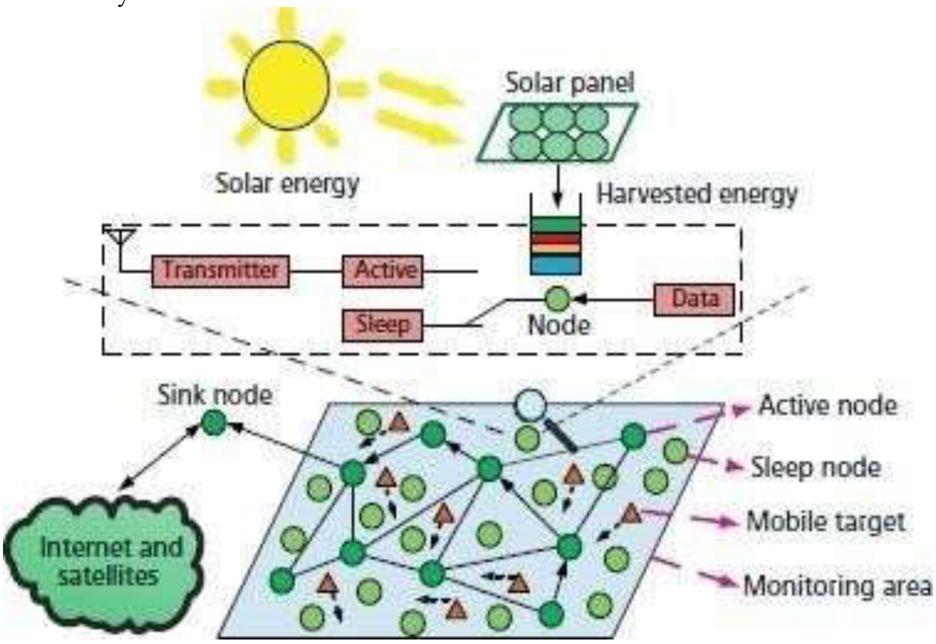

Figure 3. Collecting Energy from the Sun

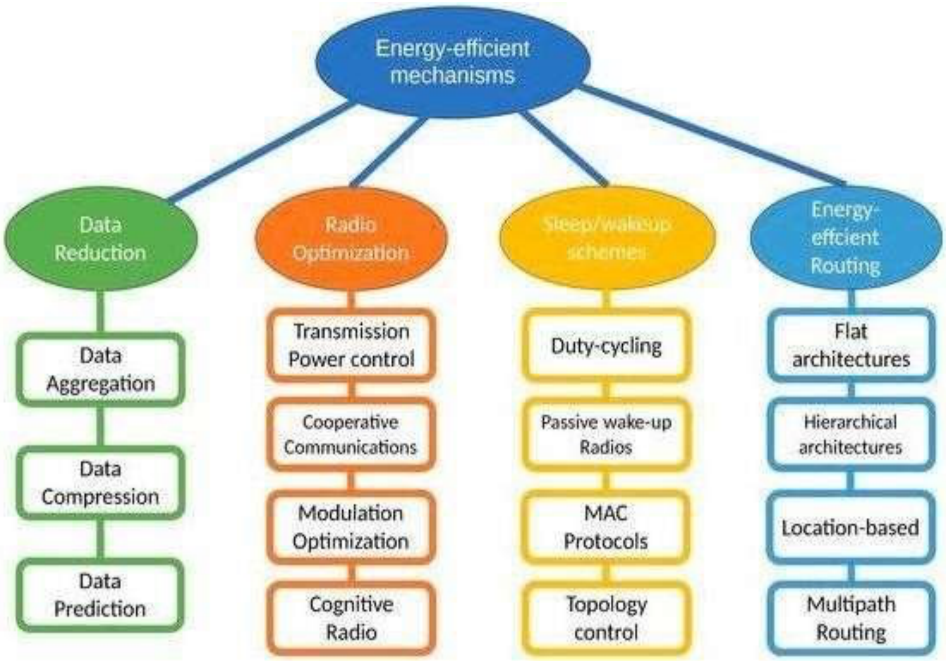

Figure 4. Taxonomy of energy efficient mechanism

2.2. Energy Hardware Module

The energy subsystem (Figure 2.4) installed on the sensor node receives energy from the surrounding environment. This subsystem includes equipment that converts ambient energy into usable electricity. The collected electricity can be used immediately to power the machine or stored for future use. When direct power from the nodes eliminates the need for batteries, the implementation of the strategy usually involves solutions for weak energy and changes in the cost of harvesting. The security system recovers energy from natural sources to meet the energy needs of the nodes, ensuring continuous operation even in environments with strong fluctuations.

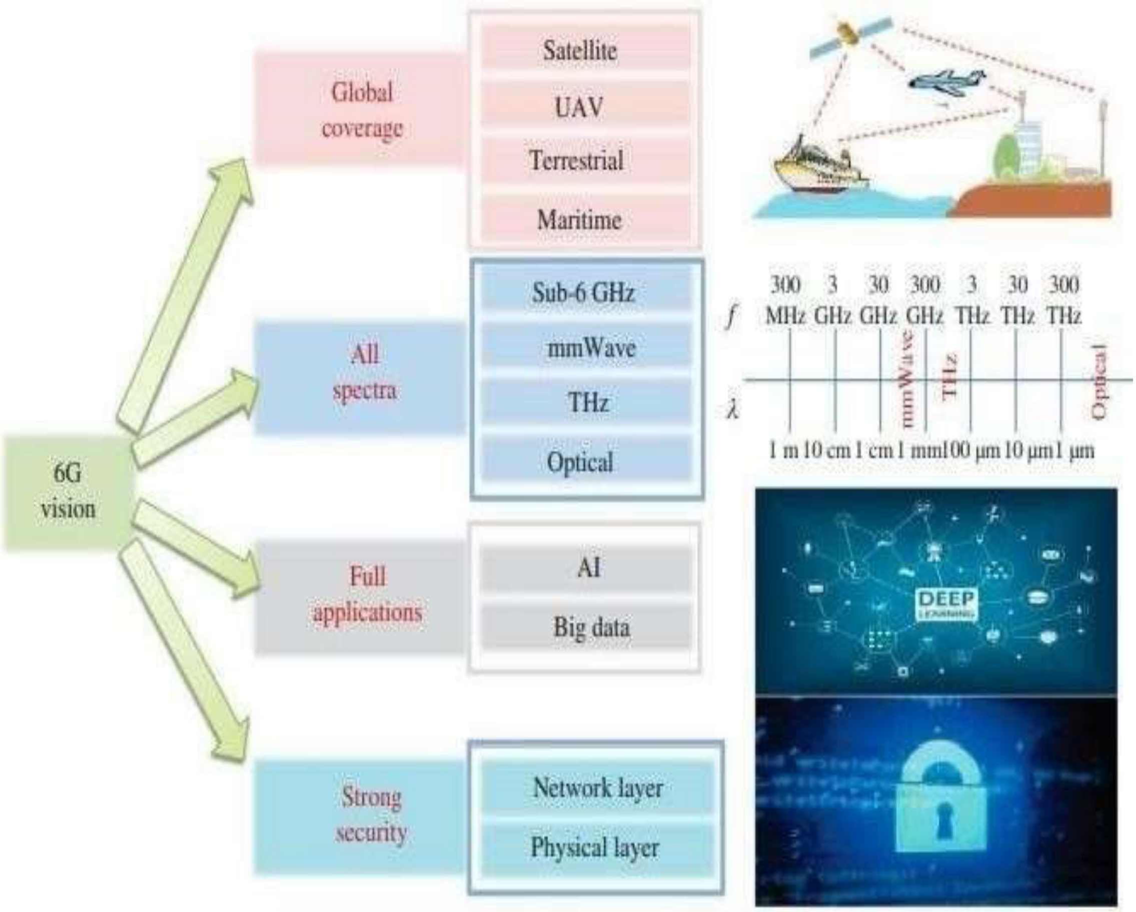

Figure 5. A vision of 6G wireless communication network

3. Results

The data was generated using the random sampling technique in Python's random module, which provides various functions to generate random numbers. More specifically, random.choice() picks a random value from a list, while random.uniform() generates a random number from a list. Their values are chosen randomly. At the same time, random.uniform() generates a random number in the weather_feature field, the value must be between 20 and 40, and the Energy_product_feature field must have a value between 100 and 500 ('high', 'medium', 'low'). * Bonus for each action ("Delivery": 10, "Sleep": -2, "Write": 5). >

Events and activities are basic properties, while weather properties and power generation are numerical. This information provides detailed information about the state of the world: conditions and activities related to solar activity, weather conditions that estimate the brightness of the day, and electrical measurement properties of the body.

Action In this case, the event corresponds to the weather (sun, cloud, or rain), while the action is related to the decision to harvest the sun. Employees are trained to use Q-learning to increase energy efficiency in the solar system. Learning parameters include Learning_rate = 0.8, discount_factor = 0.9, exploration rate = 0.2, and num_episodes = 1000. The goal is to maximize profit for each segment. Each project involves an agent choosing an action based on the current state (e.g., enable or disable the solar panel) and receiving a reward for generating electricity accordingly.

3.1. Q-table

The Q-table stores future rewards (Q-values) for two states. During Q-learning, these results are modified and optimized to improve the agent’s strategy. Finally, the Q-table estimates the optimal value for each state by capturing the agent’s response at each location. Setting the learning curve as a Q-list view can improve agent performance and encourage training of new employees. Behavior in the field. Its complexity increases with situations and operations and accordingly affects training and decision-making processes.

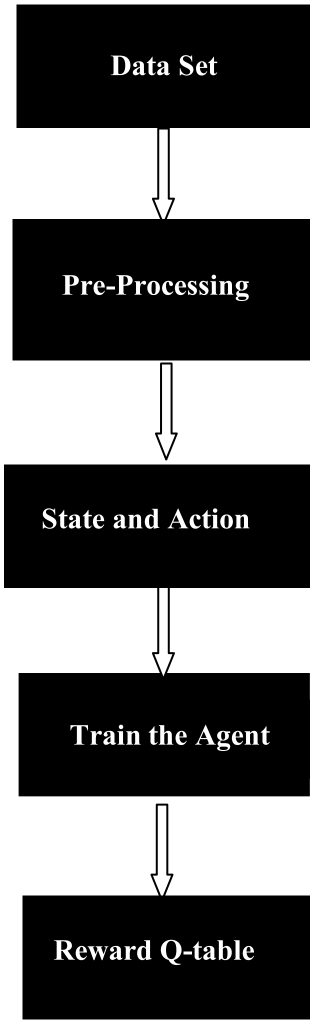

Figure 6. Proposed architecture for Q-Learning

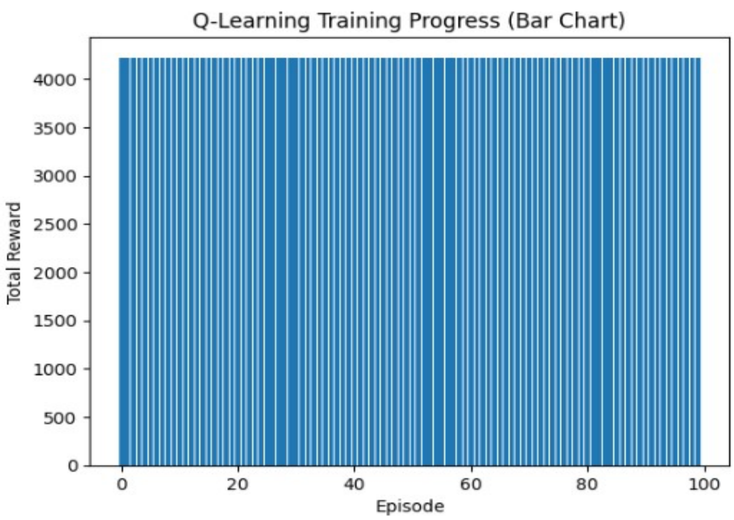

Figure 7. Q-Learning Training Progress (Bar Chart)

4. Discussion

While we're giving the details, let's talk about the applications and implications of using Q-learning to develop solar energy. Applications in Electric Energy:

Q-learning is particularly suitable for renewable energy projects such as solar energy. By learning from the data generated by the simulations, operators can make energy-efficient decisions about different weather and conditions as needed (such as when to collect energy, transmit data, or conserve energy).

And others, including digital projects such as weather and energy production. These features are based on real-world conditions where weather affects solar energy production and behavior directly affects electricity production. Education and Training :

During training, Q learner mastered the Q-table by interacting with the data many times (in this case 1000 times). Lack of training (0.8), discounting (0.9) and research (0.2) are important to balance the search for new activities with the use of existing activities to adjust energy production strategies. Good Quality and Decision Making:

The goal of training an agent is to obtain good policy; for example, the agent will learn over time that harvesting in the sun and saving energy during the rainy season will yield the best results. Challenges and Decisions :

4.1. Government and Office Challenges

Depending on the situation (such as weather) and the work (answers), the patch area expands and the size of the Q-table increases, so that we take into account the resources and work time. The difference between the simulated environment and the real environment will affect the agent's actions and content. Incorrect setup may result in slow or poor performance. Applications and Future Directions:

4.2. Pre-Employment

After graduation, Q-study employees can work in daily tasks, work according to current weather forecasts and make adjustments accordingly. * Integration with IoT and automation: Integrating IoT devices into systems can increase efficiency by improving data collection and decision making. Systematizing and ensuring sustainable energy use is still important, and future research will focus on energy management algorithms and technologies. By training synthetic workers and carefully correcting shortcomings, future advances in renewable energy can be more efficient and sustainable.

5. Conclusions

This study demonstrates the benefits of integrating green communication systems into renewable energy systems. By combining electronic devices with communication, the aim is to increase security and reduce dependency on traditional electronic devices. Considering the difference in solar energy, this study uses Q-learning to optimize the decision of collecting and using electricity. Through experiments and simulations, the method demonstrates efficiency, reduces energy consumption, and increases the reliability of the network. This algorithm outperforms existing algorithms for power distribution among sensor nodes in Wireless Sensor Networks (WSNs). It provides detailed information on promoting green communication in next-generation wireless energy networks based on energy harvesting. This study demonstrates the effectiveness of using Q-learning algorithms to optimize solar energy utilization, reduce energy consumption, and improve network reliability in the future. Future research should be extended to other renewable energy sources such as wind energy and vibration energy. Furthermore, exploring hybrid EHWSNs combining fuzzy Q-learning (FQL) with fluid dynamics control (FQLDEM) can improve network reliability. These innovations can make wireless sensor networks more efficient and stable.

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