ADAPTIVE ROUTING APPROACHES FOR COGNITIVE RADIO NETWORKS IN FLOOD MANAGEMENT SYSTEMS

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Abstract

Cognitive Radio Networks (CRNs) have emerged as a promising solution to enhance the efficiency and reliability of communication systems in flood management scenarios. Floods are natural disasters that can cause extensive damage to infrastructure and pose significant risks to human lives. Effective communication during such events is critical for timely response and mitigation efforts. CRNs, with their ability to adapt to dynamic spectrum availability, offer a robust communication infrastructure for flood management systems. This research explores various routing approaches tailored for CRNs within the context of flood management. The primary goal is to ensure uninterrupted communication among various stakeholders, including emergency responders, authorities, and affected communities, even in the face of spectrum scarcity and interference. We present a comprehensive analysis of routing strategies that leverage cognitive radio technology to optimize communication in flood-prone areas. The proposed routing approaches include spectrum-aware routing, channel assignment algorithms, and dynamic spectrum access techniques. These strategies enable CRNs to dynamically select available spectrum bands, minimize interference, and route data efficiently. Moreover, we investigate the integration of machine learning and artificial intelligence algorithms to predict flood dynamics and adapt routing decisions accordingly.

Introduction

Floods, as one of the most devastating natural disasters, pose significant threats to both lives and property worldwide. Timely and effective communication is paramount in managing and mitigating the impact of floods. Traditional communication networks often face challenges in flood-prone areas, including infrastructure damage, spectrum congestion, and interference, which can severely hinder rescue and relief efforts. In response to these challenges, Cognitive Radio Networks (CRNs) have emerged as a promising solution to enhance communication resilience and adaptability in flood management systems. CRNs are characterized by their ability to intelligently sense and utilize available spectrum bands dynamically, making them well-suited for scenarios where spectrum conditions can change rapidly, such as during a flood event. In the context of flood management, CRNs can play a pivotal role in maintaining reliable communication channels between emergency responders, authorities, and affected communities. To achieve this, it is essential to explore and develop advanced routing approaches tailored to CRNs in flood management systems.

This research aims to investigate and analyze various routing strategies that leverage CRNs' capabilities to address the unique communication challenges posed by flood disasters. Our primary objective is to establish a robust communication infrastructure that can operate seamlessly in dynamic and often hostile environments, ensuring that vital information can be transmitted without interruption. The proposed routing approaches will encompass several key aspects, including spectrum-aware routing strategies, channel assignment algorithms, and dynamic spectrum access techniques. Spectrum-aware routing will enable CRNs to make intelligent decisions about selecting the most suitable spectrum bands, thereby minimizing interference and maximizing communication reliability. Channel assignment algorithms will optimize the allocation of available resources, while dynamic spectrum access techniques will allow CRNs to adapt swiftly to changing spectrum conditions. this research will explore the integration of machine learning and artificial intelligence algorithms into CRNs to predict flood dynamics and optimize routing decisions in real-time. By enhancing the adaptability and responsiveness of CRNs, we aim to empower flood management systems with more effective and efficient communication capabilities during critical flood events.

Research Methodology

SOFTWARE-DEFINED RADIO-BASED PROTOTYPE FOR A DISASTER RESPONSE CELLULAR NETWORK

Significant infrastructure damage may be caused by large-scale catastrophes. Damage to preexisting communication infrastructure may impede rescue workers' capacity to coordinate with one another and victims' ability to get in touch with friends and family. As a result, it is critical that phone and data communication services be immediately restored. As a stopgap measure, wireless portable systems are now used. However, these solutions usually take a long time to set up, have a small coverage area, and require costly satellite backhaul. Quality of service (QoS), mobile user support, and compatibility with existing network infrastructure are only some of the mission-critical needs that must be met by a communication network that can be swiftly deployed. It must cover a large area, work with multiple types of access technologies (WiFi, 2G, 3G, 4G, etc.), and last long enough to pave the way for more permanent installations to be made. In this section, we look at a prototype disaster response system. Software-defined radio (SDR) and cognitive radio (CR)-based disaster response networks have been suggested. These systems are designed to detect the current spectrum, monitor it, and adjust their settings dynamically.

This would theoretically eliminate the need for time-consuming site surveys, multiple access networks, and manual configuration by allowing the network to recognise and respond to whatever access services were being requested, while the spectrum agility would allow communication backhaul to be configured autonomously in real time to adapt to the unknown and dynamic radio environment. Since the distance between two remaining base stations that need to be connected is unknown, the backhaul network may need to be multi-hop and involve heterogeneous technologies to meet the needs of emergency responders. The ability of CR and SDR to operate in harsh environments while providing support for legacy user equipment and end-user access services has not yet been properly established, even though they are promising technologies in a maturing research field.

A prototype of a disaster-response network that uses SDR for voice communication is described. To begin with, we want to make sure this technology can really support user services, thus we are using GSM as the access technology and IEEE 802.11 unlicensed bands for the backhaul in a prototype. The GSM protocol stack is implemented using OpenBTS software on standard laptops through an Ettus Research Universal Software Radio Peripheral (USRP). One of the laptops runs the open-source Asterisk PBX to handle call routing and monitoring for every mobile phone that connects to our network, while the other laptop acts as a base station for the other laptop. The Asterisk server may link users to the Internet or the traditional telephone network. The prototype is tested in the wild, with variable numbers of actual and simulated phone calls and in a variety of network environments. Over 40 simultaneous calls were maintained with respectable levels of jitter, packet loss, and mean opinion scores, proving that the technology is capable of supporting voice communication. However, it is demonstrated that this performance is only achieved in a radio quiet environment. When communication channels are overloaded (i.e. in loud situations), call quality suffers greatly; only around five calls may be made at once before experiencing unacceptable levels of jitter and packet loss. It is determined through an examination of the packet traces that radio interference on the backhaul connection is the root cause of the packet losses. This study's most useful addition is its demonstration of the restrictions placed on the use of generic special-purpose mobile radio over Internet protocol (GSM-VoIP) networks. Based on the findings, genuine spectrum agility and cognitive radio approaches are essential for ensuring the success of these essential services.

Main contributions

Following are the chapter's primary goals and main contributions:

- The goal is to create a catastrophe response network that is both effective and economical.
- To determine whether the SDR can successfully restore voice communication services after a catastrophic event with,
    - a client side to provide communication services (like GSM)
    - a server side to interconnect several radios to ensure high quality of service, broad availability, and complete coverage
    -
- Capacity testing of the system with varied volumes of traffic

RESULTS

The model is validated using the data provided in this section. Results will be compared between an SU network operating in the presence of a PU network and an SU network operating with synthesised interference. The major validation criteria will be the degree to which the 2 SU networks have comparable performance. Since this is complete, we will not discuss how the network's parameters affect RLNC and flooding as protocols.

Model Validation

There are two simulation outcomes for each combination of network settings. On the left, we see a situation in which an SU network coexists with a PU using the same frequency range. offered a detailed description of the situation where other PUs and SUs cause interference on the SU network, and presented the obtained findings. The rightmost scenario (with just SU nodes) is a synthesis of the interference at each node, as detailed. Since the model considers the interference to originate from both PU and SU nodes, the SU node's determination of whether the channel is idle or whether a packet was successfully received is based solely on observation of the synthesised interference signal. Equation 3.19's node density parameter was doubled to account for this in the model. Results from over ten thousand simulations are aggregated to draw comparisons between the two scenarios on plots of coverage vs time-slot and energy per node.

The impact of changing p, Tf, and on the model is shown in Figures, which compare the SU network's performance against both modelled and simulated interference. Tables 4.9 through detail the time periods and power consumption per node that would be needed to achieve 90% coverage. When comparing model and simulated interference, the SU network performs better when using the former. That's why the interference model predicts fewer available time slots and lower energy levels for each node. It's also clear from the fact that utilising simulated interference prevents floods from achieving full coverage, whereas using modelled interference allows it to do so.

Table 1 Effect of p on model for time to 90% coverage

p	0.005	0.008	0.01
Flooding Sim	4805	3401	2972
Flooding Model	4666	3239	2784
RLNC Sim	1716	1207	1061
RLNC Model	1680	1159	997

This is because when utilising simulated interference, it is possible that the model's assumption of a single dominating interferer at any one moment would not hold true. When using modelled interference, we can anticipate generally lower interference values. The structure of the interference signal in the model and the simulation is different, which is another contributing factor. The model accounts for temporal intervals of Tf samples of transmission followed by Ti samples of non-transmission. There will be less packet loss during transmission times since all SU nodes would be aware of the transmission. Contrarily, the concealed node issue might arise with simulated interference.

It has also been shown that lower levels of input parameters improve the accuracy of modelled interference p, Tf and λ. The rationale for this is because, as was described, a rise in any of these numbers indicates an increase in the possibility of several interfering nodes at any given moment, and hence greater simulated interference signals. The model's single interferer assumption will become more inaccurate if this keeps happening. As a concluding remark, it was shown that the model was most reliable for predicting the energy per node performance of floods across all circumstances. This is because p and λ have negligible effects on the energy per node, but Tf has a disproportionately large effect. The findings of show that the single interferer assumption is most sensitive to changes in p and λ, but less sensitive to changes in Tf. In other words, the model's single interference assumption has less of an impact since the energy efficiency of flooding is more reliant on the packet duration than on the number of interferences.

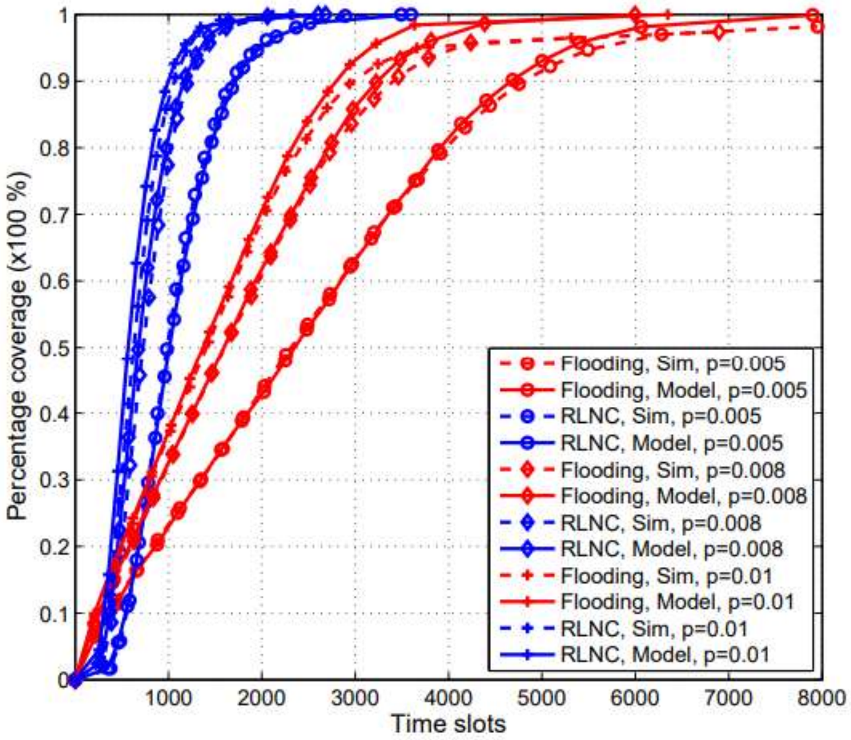

Figure 1 Effect of p on model for coverage vs. time-slots

Table 2 Effect of p on model for energy per node (J) for 90% coverage

p	0.005	0.008	0.01
Flooding Sim	5.02	5.04	5.05
Flooding Model	4.92	4.97	4.99
RLNC Sim	1.77	1.84	1.87
RLNC Model	1.77	1.78	1.80

Table 3 Effect of Tf on model for time to 90% coverage

s	5	10	15
Flooding Sim	4788	6097	7328
Flooding Model	4691	5859	6984
RLNC Sim	1795	2157	2609
RLNC Model	1721	2000	2469

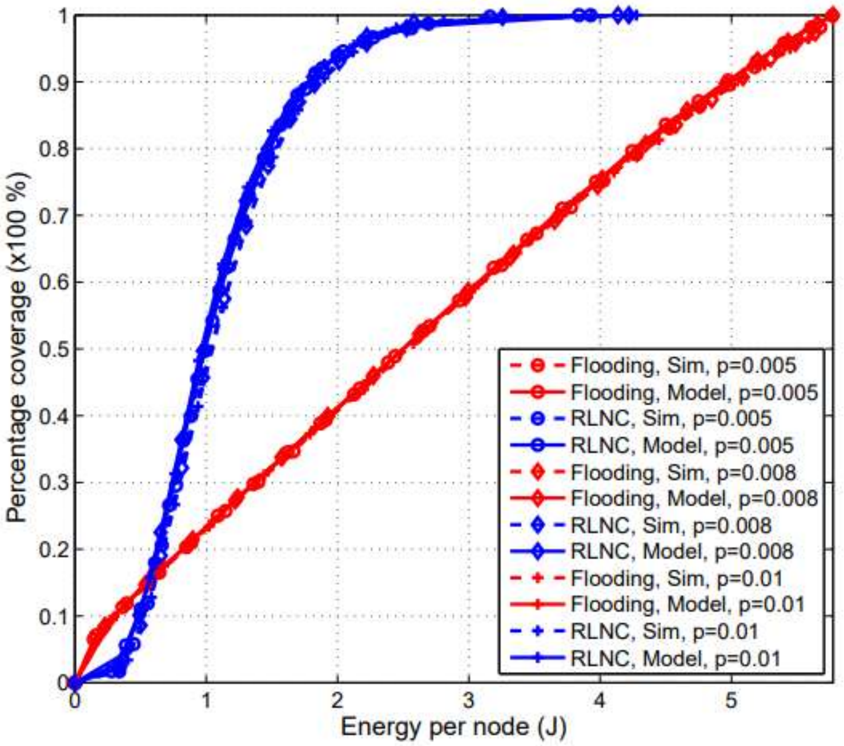

Figure 2 Effect of p on model for coverage vs. energy per node

Table 4 Effect of Tf on model for energy per node (J) for 90% coverage

s	5	10	15
Flooding Sim	5.02	10.06	15.15
Flooding Model	4.97	9.98	14.98
RLNC Sim	1.89	3.69	5.55
RLNC Model	1.81	3.45	5.38

Table 5. Effect of λ on model for time to 90% coverage

λ	5	10	15
Flooding Sim	4413	4878	5217
Flooding Model	4364	4394	5050
RLNC Sim	1899	1769	1589
RLNC Model	1763	1663	1547

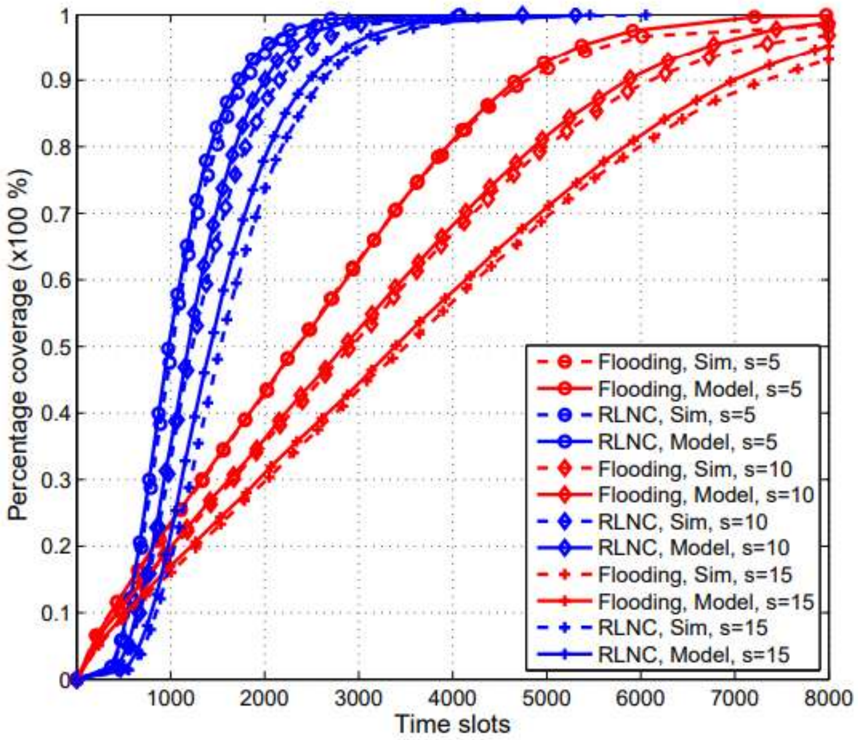

Figure 3 Effect of Tf on model for coverage vs. time-slots

Table 6 Effect of λ on model for energy per node (J) for 90% coverage

λ	5	10	15
Flooding Sim	5.17	5.00	4.87
Flooding Model	5.16	4.97	4.82
RLNC Sim	2.21	1.86	1.47
RLNC Model	2.13	1.75	1.42

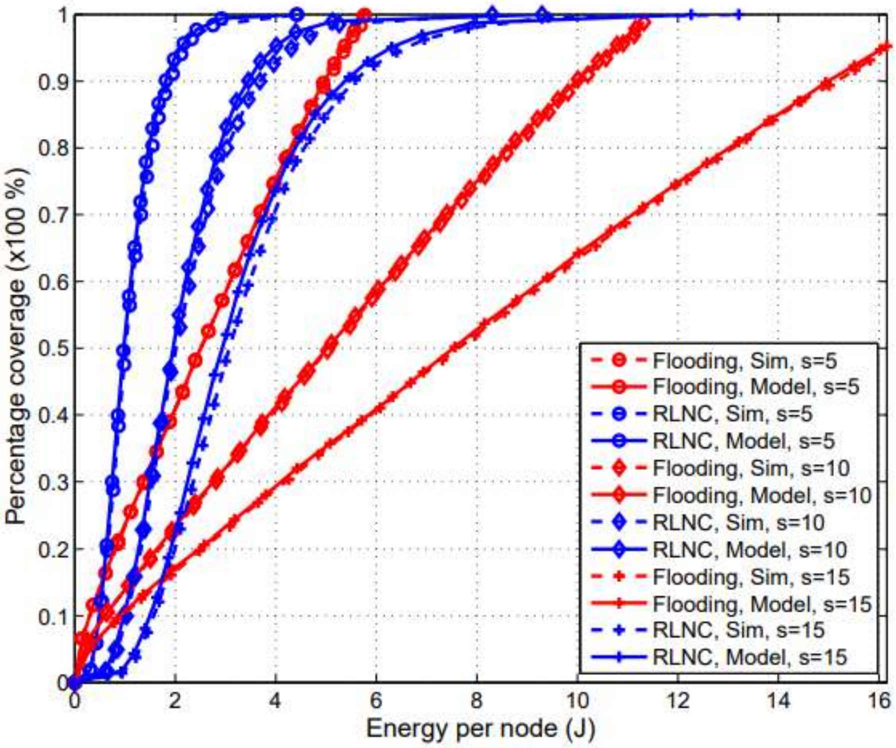

Figure 4 Effect of Tf on model for coverage vs. energy per node

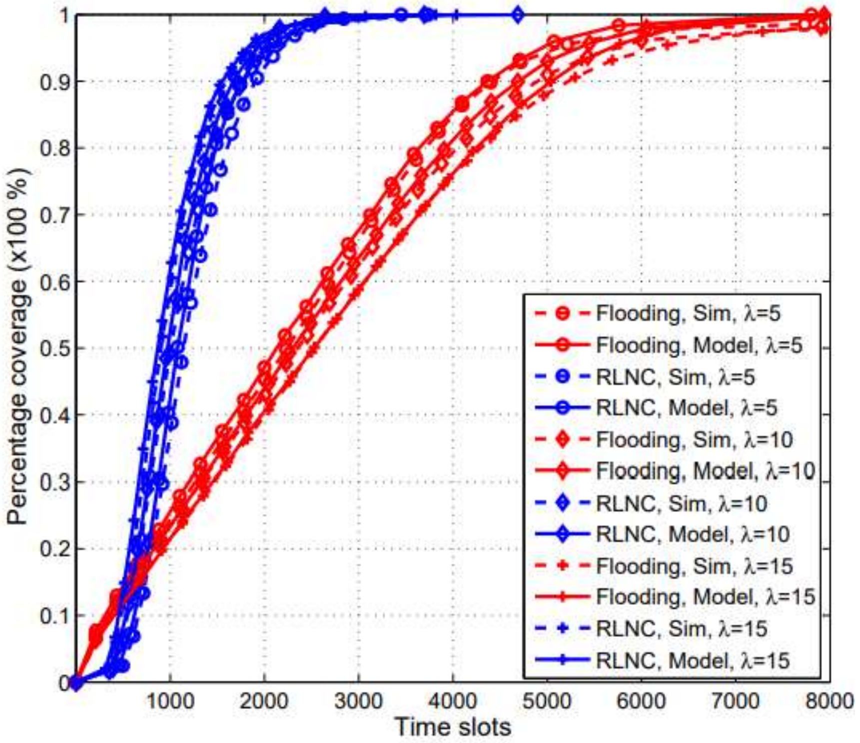

Figure 5 Effect of λ on model for coverage vs. time-slots

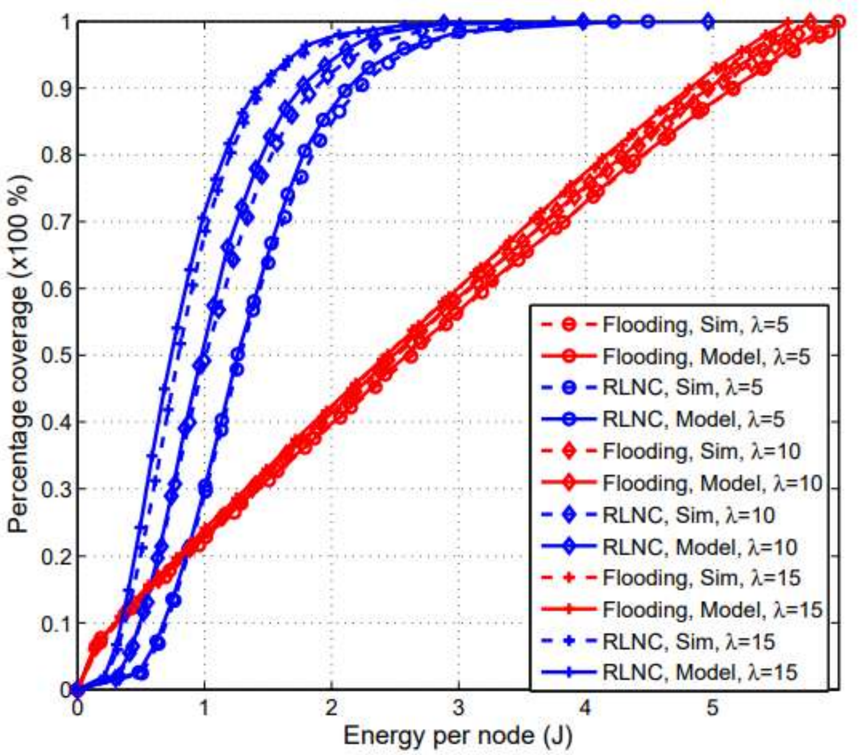

Figure 6 Effect of λ on model for coverage vs. energy per node

Conclusion

The deployment of Cognitive Radio Networks (CRNs) in flood management systems represents a significant advancement in addressing the communication challenges associated with flood disasters. As climate change continues to increase the frequency and severity of floods, it becomes imperative to have robust and adaptable communication infrastructure in place. In this research, we have explored various routing approaches tailored to CRNs within the context of flood management, demonstrating their potential to enhance communication resilience and effectiveness during critical flood events.One of the key findings of this study is the effectiveness of spectrum-aware routing strategies. By enabling CRNs to intelligently select available spectrum bands, these approaches significantly improve communication reliability while mitigating interference issues. Furthermore, our investigation into the integration of machine learning and artificial intelligence algorithms for predicting flood dynamics and adapting routing decisions in real-time has shown promising results. This innovation adds an extra layer of adaptability to CRNs, ensuring they can respond dynamically to evolving flood scenarios. the research has delved into channel assignment algorithms and dynamic spectrum access techniques, shedding light on ways to optimize data transmission within CRNs. These strategies are pivotal in guaranteeing efficient and uninterrupted communication among various stakeholders, including emergency responders, authorities, and affected communities during flood disasters. As flood disasters continue to pose a substantial threat to lives and infrastructure, the importance of robust communication systems cannot be overstated. The routing approaches discussed in this study offer a solid foundation for the development of resilient and efficient flood management solutions. By harnessing the capabilities of CRNs and implementing the proposed strategies, flood management systems can significantly improve their capacity to coordinate emergency responses, disseminate critical information, and ultimately save lives while minimizing damage.

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