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A Framework for Enhancing Online Food Delivery Systems with Fog Computing

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Abstract

This paper presents a fog computing framework designed to enhance the performance of online food delivery systems by reducing latency and improving packet transfer efficiency. Unlike traditional cloud-based systems, which often suffer from high latency due to centralized data processing, the proposed framework leverages fog computing to distribute processing closer to users, thereby minimizing delays and enhancing service responsiveness. A key contribution of this framework is its strategic approach to service placement, which delineates the optimal distribution of services between cloud and fog environments. This strategic distribution aims to balance computational load and enhance overall service efficiency. Although the framework is currently at a conceptual stage, it lays out a comprehensive plan for future practical implementation. Subsequent work will involve deploying the framework in real-world settings, evaluating its performance, collecting user feedback, and conducting security assessments to confirm its benefits and refine its functionalities. This work provides a foundational approach for leveraging fog computing to advance online food delivery systems, setting the stage for future developments in this area.

Keywords: Fog Computing, Cloud Computing, Food Delivery System, Latency, Service Placement

1. Introduction

The food delivery industry has undergone significant transformation due to the rising demand for convenience and speed [1]. As consumer expectations increase, traditional food delivery systems face mounting challenges in managing order fulfillment, optimizing delivery routes, and ensuring timely service [2]. These systems, which largely depend on centralized cloud-based architectures, often struggle with limitations related to latency, real-time data processing, and resource management.

While centralized cloud computing offers considerable power, it introduces delays because of the distance data must travel between users and servers. This latency hampers the system's ability to make quick decisions regarding order assignments and route adjustments. Moreover, the vast amount of real-time data—ranging from order specifics to traffic conditions—can overwhelm traditional systems, potentially affecting their responsiveness and accuracy.

Resource management and scalability further complicate the efficiency of food delivery operations. Traditional systems may find it difficult to adapt dynamically to fluctuating demand, resulting in suboptimal allocation of delivery partners and increased operational costs. Additionally, security and privacy concerns present significant challenges, as centralized data storage increases the risk of data breaches and unauthorized access.

Fog computing offers a promising solution to these issues. By extending computational and storage capabilities to the network edge, fog computing addresses many of the shortcomings of centralized systems [3]. This decentralized approach allows for real-time data processing closer to the source, reducing latency and enhancing decision-making speed. Fog computing also supports scalable and flexible resource management, improves security by distributing data across multiple nodes, and integrates seamlessly with Internet of Things (IoT) devices to further optimize delivery operations.

This paper examines how fog computing can be leveraged to enhance food delivery systems by tackling key challenges such as latency, real-time data processing, and resource management. As an early-stage investigation, this work presents a conceptual framework and outlines the structure for integrating fog computing into food delivery operations. The goal is to lay the foundation for future research and practical implementation, paving the way for the development of more efficient, responsive, and scalable food delivery systems.

The paper is structured as follows: Section 2 provides a literature survey, Section 3 articulates the problem statement, Section 4 introduces the proposed framework, Section 5 outlines expected results and challenges, and Section 6 concludes with insights and directions for future research.

2. Literature Survey

Fog computing has been widely adopted across various applications, significantly enhancing their performance. Many studies have utilized fog computing in surveillance systems to enable real-time processing. For instance, Chen et al. (2016) propose a dynamic video stream processing scheme [4] for urban traffic surveillance, leveraging Fog Computing for real-time processing and decision-making. It investigates using a simplified single-target tracking algorithm for multi-target scenarios, with experimental results demonstrating its potential for smart urban surveillance applications. Similarly, Mosaif and Rakrak (2021) introduce a real-time video surveillance system [5] for Smart Cities that employs mobile camera nodes on transport vehicles, leveraging Fog Computing and Wireless Visual Sensor Networks. The proposed camera node selection method for tracking is tested in simulations, yielding promising results for effective urban surveillance. Additionally, Nurnoby and Helmy (2023) present a deep learning-based framework [6] for smart video surveillance using Fog Computing, supporting real-time video processing. The framework includes modules for video capture with Raspberry Pi cameras, action recognition on NVIDIA Jetson Nano devices across two fog layers, and security response generation, with experiments confirming its effectiveness for real-time applications.

Fog computing also plays a crucial role in healthcare applications. Paul et al. (2018) propose the use of Fog Computing for monitoring patients with chronic diseases using wireless sensors [7], enhancing efficiency by processing data locally and reducing dependency on cloud computing. It also addresses the security and deployment challenges associated with this approach. Furthermore, Tuli et al. (2020) introduce HealthFog [8], a framework combining ensemble deep learning with Edge computing for efficient heart disease analysis. This approach reduces latency and improves performance compared to cloud-based IoT systems, and is evaluated across various metrics using FogBus. Another study by Kishor et al. (2021), presents a fog computing model integrated with cloud computing and IoT sensors to reduce latency in healthcare [9]. By employing a random forest machine learning approach, the model improves real-time monitoring, reducing latency by 92%-95% and minimizing patient visits. Nancy et al. (2023) introduce a fog-assisted smart healthcare system [10] for diagnosing cardiovascular diseases, combining a fuzzy inference system with a gated recurrent unit (GRU) model. By processing healthcare data at the fog layer, the system achieves a classification accuracy of 99.125% and reduces latency, response time, and jitter compared to cloud-only solutions. This approach optimizes time-critical healthcare applications by leveraging deep learning within a decentralized fog computing framework.

Fog computing has also been leveraged to improve traffic management. Peixoto et al. (2023) present FogJam [11], a fog computing service designed to detect traffic congestion at the edge of vehicular networks, reducing data transmission to the cloud. This approach decreases network usage by 70% while maintaining high detection accuracy in dense traffic scenarios. The paper Hu et al. (2020) proposes an intelligent fog-based approach [12] for IF-RANs to address the challenges of 5G networks. It employs LSTM with an attention mechanism for traffic prediction and cognitive caching to reduce communication delays. The fog layer enhances real-time prediction accuracy and lowers latency, thereby improving the overall performance of 5G networks. Moreover, Tang et al. [2019] introduce a fog computing-based architecture for smart traffic signal [13] control to address latency issues in centralized systems. By processing traffic data at the edge, where it is generated, the system uses a genetic optimization algorithm for real-time phase timing at intersections, while regional optimization tasks are handled by the cloud. Simulation results indicate significant improvements in average traffic duration time compared to existing methods.

Despite these advancements, to the best of author's knowledge, no existing work has proposed leveraging fog computing to enhance the performance of online food delivery systems. Typically, orders placed by users are fulfilled by nearby restaurants, with delivery associates allocated from the surrounding area to ensure quick and efficient service. By processing this information locally within a fog computing layer, substantial traffic to the cloud can be reduced and latency minimized. This paper introduces a framework for a fog-based food delivery system that optimizes these processes for better efficiency and performance.

3. Problem Statement

Online food delivery systems are integral to modern consumer convenience but face significant performance challenges. Centralized cloud computing architectures, which are commonly used in these systems, introduce latency and inefficiencies due to the distance data must travel between users and central servers. This can adversely impact real-time order processing, tracking, and overall user satisfaction.

To quantify these issues, we define and analyze the following problems:

3.1. Latency in Centralized Systems

Latency ($L_{\{cloud\}}$) in a centralized cloud-based system can be expressed as:

$$L_{\{cloud\}} = T_{\{transmission\}} + T_{\{processing\}} + T_{\{queuing\}} + T_{\{propagation\}} \tag{1}$$

Where	$T_{\{transmission\}}$	is the time taken to transmit data over the network.
	$T_{\{processing\}}$	is the time taken by the server to process the request.
	$T_{\{queuing\}}$	is the time spent waiting in the queue at the server.
	$T_{\{propagation\}}$	is the time taken for data to travel from the client to the server and back.

In a centralized system, the propagation delay is often significant due to the distance from the user to the cloud server, leading to:

$$L_{\{cloud\}} \approx \frac{D_{\{cloud\}}}{C_{\{network\}}} + T_{\{processing\}} + T_{\{queuing\}} + T_{\{transmission\}} \tag{2}$$

Where	$D_{\{cloud\}}$	is the distance between the user and the cloud data center.
	$C_{\{network\}}$	is the signal speed.

Fog computing aims to address these issues by bringing computation closer to the end-users. Since fog nodes are closer to users, propagation delay is minimized, leading to:

$$L_{\{fog\}} \approx \frac{D_{\{fog\}}}{C_{\{network\}}} + T_{\{processing,fog\}} + T_{\{queuing,fog\}} + T_{\{transmission,fog\}} \tag{3}$$

Where	$T_{\{transmission,fog\}}$	is the time taken to transmit data to fog node.
	$T_{\{processing,fog\}}$	is the time taken by the fog server to process the request.
	$T_{\{queuing,fog\}}$	is the time spent waiting in the queue at the fog server.
	$D_{\{fog\}}$	is the reduced distance due to proximity of fog nodes.

3.2. Packet Transfer Efficiency

In centralized systems, packet transfer efficiency can be $\mathrm{E}_{\{cloud\}}$ reduced due to increased latency and potential network congestion

$$\mathrm{E}_{\{cloud\}} = \frac{\{1 - \mathrm{P}_{\{loss\}}\}}{\mathrm{T}_{\{transfer\}}} \tag{4}$$

Where	$\mathrm{P}_{\{loss\}}$	is the rate of lost packets.
	$\mathrm{T}_{\{transfer\}}$	is the time taken to transfer packets from the user to the server and back.

Packet transfer efficiency in a fog-based $\mathrm{E}_{\{fog\}}$ system can be improved and is expressed as:

$$\mathrm{E}_{\{fog\}} = \frac{\{1 - \mathrm{P}_{\{loss,fog\}}\}}{\mathrm{T}_{\{transfer,fog\}}} \tag{5}$$

Where	$\mathrm{P}_{\{loss,fog\}}$	is the packet loss rate in the fog network.
	$\mathrm{T}_{\{transfer,fog\}}$	is the time for data transfer between the fog node and the user.

3.3. User Utility

In an online food delivery system, user utility is influenced by several factors, primarily latency and packet transfer efficiency. Higher latency can negatively impact user satisfaction. Higher efficiency ensures accurate and quick data transfer, positively impacting user satisfaction. The overall utility for a user can be expressed as a function of both latency and packet transfer efficiency. A combined utility function can be given as:

$$U_i = \frac{\beta\, E_i}{1 + \alpha L_i} \tag{6}$$

Where β represents the positive impact of efficiency on utility and α represents the negative impact of latency on utility. As packet transfer efficiency increases, the utility increases and as latency increases, the utility decreases.

3.4. Objective

Maximize the total utility U for all users in the system, where the utility for each user depends on latency and packet transfer efficiency. The objective can be formulated as:

$$\text{maximize U} = \sum_{i=1}^{N} U_i \tag{7}$$

$$L_{\{fog\}} \leq L_{\{Thresh\}} \tag{8}$$

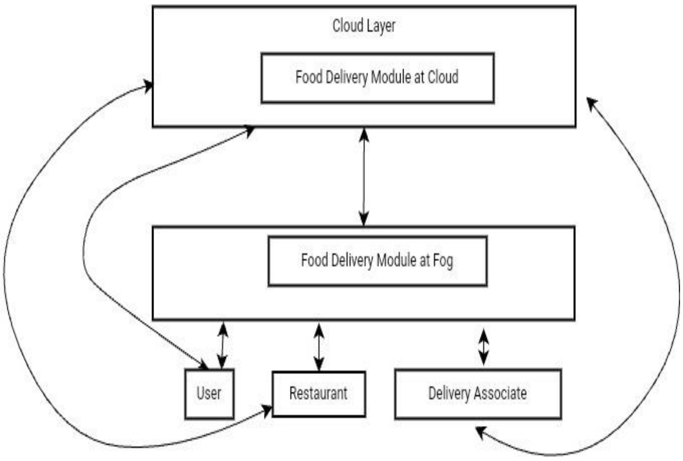
$$E_{\{fog\}} \geq E_{\{Thresh\}} \tag{9}$$

where U_i represents the utility for user i, and N is the total number of users. $L_{\{fog\}}$ is the latency in the fog computing system and $L_{\{thresh\}}$ is the maximum acceptable latency. $E_{\{fog\}}$ is the packet transfer efficiency in the fog system and $E_{\{Thresh\}}$ is the minimum acceptable efficiency.

4. Proposed framework

In this section, we propose a three-layer architecture for an online food delivery system leveraging fog computing to optimize communication, processing, and resource management. The framework aims to efficiently manage order placements, restaurant notifications, and delivery assignments through a hybrid cloud-fog architecture. The system minimizes latency by handling time-sensitive tasks at the fog layer, while more complex operations and data storage are managed by the cloud layer. This approach balances real-time response with large-scale data handling, which is critical for the efficient operation of the online food delivery system.

Figure: 1 Architecture of the Fog Enabled Online Food Delivery System



4.1. Architecture Overview

Figure:1 shows the architecture of the proposed framework. It consists of three interconnected layers namely user layer, fog layer and cloud layer, that enable efficient communication and processing for an online food delivery system:

User Layer: This layer consists of users, restaurants, and delivery associates. Users place orders through the system and receive the items. Restaurants prepare the ordered food, while delivery associates handle the delivery process. This layer interacts directly with the fog and cloud layers to initiate and complete transactions, providing order status updates and tracking.

Fog Layer: The fog layer processes real-time requests from the user layer, such as order placement, restaurant availability checks, and delivery assignments. By handling these time-sensitive tasks locally, the fog layer reduces latency and ensures fast response times. It also communicates with the cloud layer to synchronize data and manage updates.

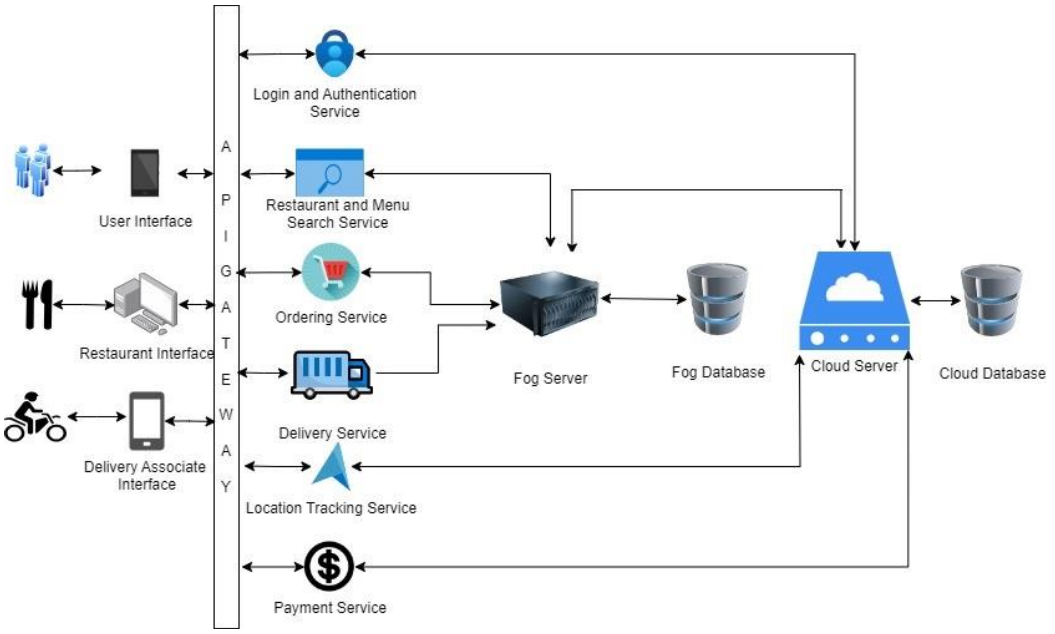
Cloud Layer: The cloud layer manages long-term data storage and computationally intensive tasks, such as maintaining user history, managing restaurant data, and running analytics. While the fog layer handles real-time tasks, the cloud layer ensures scalability and efficient data management by processing and storing large-scale information. The cloud and fog layers work together to maintain system-wide consistency and reliability.

4.2. Service Placement

In the proposed online food delivery system, services are strategically placed across the fog and cloud layers to optimize performance and resource usage. Figure:2 shows the service placement of the proposed framework.

The fog system manages user requests, restaurant availability, and delivery associate assignment. When a user places an order, it is first authenticated by the cloud system before being forwarded to the fog for processing. The fog queries nearby restaurants, notifies the selected restaurant, and assigns a delivery associate. The cloud layer handles payment processing, stores order details, and updates real-time order tracking. This division ensures low-latency processing at the fog layer while the cloud system manages resource-heavy tasks like payments and tracking.

Figure: 2 Service Placement for Fog Enabled Online Food Delivery System



4.3 Communication Flow

Figure:3 visually represents the interaction and division of tasks between the fog and cloud systems in the online food delivery system. It showcases the end-to-end process from the moment a user places an order to the final delivery, outlining the responsibilities of each layer and the communication flow between them.

User Request and Authentication: When a user places an order, the request is first directed to the cloud system. The cloud layer is responsible for handling user authentication to verify the identity of the customer. Once authenticated, the request is allowed to proceed to the next stage.

Forwarding to Fog for Local Processing: Once the user identity is confirmed, the cloud system forwards the order details to the fog system, which is responsible for handling time-sensitive, local tasks. The fog layer queries the database to find available nearby restaurants that can fulfill the order and serves the users about the received information.

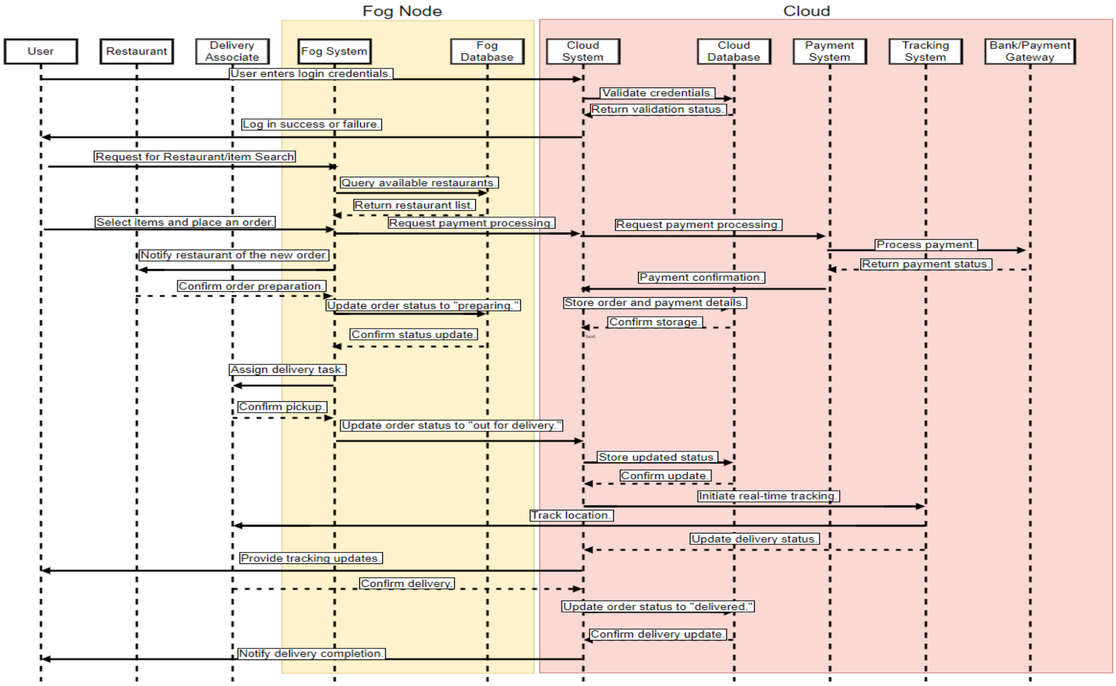
Payment Processing and Order Storage: After the user places the order, the **cloud system** handles payment processing, Simultaneously, the order details are stored in a centralized database within the cloud system for future reference and data analytics.

Restaurant Notification and Delivery Assignment: After payment confirmation by the cloud system, the fog system sends a notification to the selected restaurant to prepare the order. It also assigns a delivery associate to pick up the order once it is ready.

Order Status Updates and Tracking: Throughout the process, the fog system keeps the cloud system updated on the order's status. The cloud system, in turn, manages real-time tracking through its tracking module, providing the user with updates on the progress of their order, including the preparation status, pickup, and delivery.

Final Delivery Confirmation: Once the delivery associate has successfully delivered the order to the user, the cloud system receives confirmation from the fog system. The cloud then updates the centralized database, finalizing the transaction and storing delivery details for future reference or analysis.

Figure: 3 Communication Flow of the Fog Enabled Online Food Delivery System



5. Results and Discussion

The proposed fog computing framework for an online food delivery system, while still in the theoretical phase, is expected to achieve notable improvements in various performance metrics. This section discusses the anticipated results and their implications.

5.1 Expected Improvements

Latency Reduction: The fog computing framework is anticipated to substantially lower latency compared to centralized cloud-based systems. This reduction is attributed to the proximity of fog nodes to end-users, which minimizes data travel distances. The expected improvement in latency can be calculated as:

$$\Delta \mathrm{L} = \mathrm{L}_{\{\mathrm{cloud}\}} - \mathrm{L}_{\{\mathrm{fog}\}} \tag{10}$$

Packet Transfer Efficiency: The framework is expected to enhance packet transfer efficiency by reducing packet loss and accelerating data transfer speeds within the fog network. The anticipated increase in efficiency can be expressed as:

$$\Delta \mathrm{E} = E_{\{\mathrm{fog}\}} - \mathrm{E}_{\{\mathrm{cloud}\}} \tag{11}$$

User Utility: The overall utility of users is expected to increase with the fog computing framework compared to the traditional cloud-based system. The increased utility is anticipated due to the combined effects of reduced latency and enhanced packet transfer efficiency. This improvement in utility can be expressed as:

$$\Delta \mathrm{U} = U_{\{\mathrm{fog}\}} - \mathrm{U}_{\{\mathrm{cloud}\}} \tag{12}$$

5.2 Challenges and Limitations

The practical implementation of the fog computing framework involves several significant challenges and limitations. One major challenge is managing multiple fog nodes, which requires complex coordination to ensure effective resource allocation, efficient load balancing, and reliable communication between nodes. These complexities must be carefully addressed to maintain high system performance and reliability. Another critical issue is scalability. As the system expands with additional users and nodes, maintaining consistent performance and efficiency becomes increasingly difficult. The framework must be designed to handle such growth without significant service degradation or stability problems. Additionally, the distributed nature of fog computing introduces potential security vulnerabilities. Safeguarding data and ensuring secure communication between fog nodes are crucial to prevent unauthorized access and data breaches. Overcoming these challenges requires meticulous planning, robust security measures, and scalable design solutions to ensure the successful deployment and operation of the framework.

6. Simulation Tools

To evaluate the proposed fog computing framework for the online food delivery system, several simulation tools are available to model and analyze various aspects of system performance:

NS-3 and OMNeT++: These tools are used for network simulation and performance analysis. They provide robust environments for assessing network behavior, packet transfer efficiency, and overall performance.

iFogSim and FogFlow: Specifically designed for fog computing simulations, these tools offer comprehensive models for different aspects of fog computing environments, such as resource management, latency, and scalability**.**

MATLAB/Simulink: This tool is employed for algorithm modeling and system performance evaluation, allowing for detailed analysis and optimization of algorithms within the framework.

For the evaluation of the fog computing framework tailored for the online food delivery system, **iFogSim** will be utilized as the primary simulation tool. **iFogSim** is a well-regarded simulator for fog and edge computing environments, offering extensive models for resource management, latency, and scalability. It enables the simulation of complex scenarios involving multiple fog nodes and varied network configurations. Consequently, **iFogSim** is particularly suited for analyzing the impact of different system configurations on user utility, latency, and packet transfer efficiency. By leveraging **iFogSim**, we can effectively model and assess the performance of the fog computing framework under diverse conditions, ensuring a thorough evaluation of the system's design and optimization.

7. Conclusion and Future Work

In conclusion, the proposed fog computing framework for the online food delivery system demonstrates significant potential to enhance user experience by mitigating latency issues and improving packet transfer efficiency through localized processing and distributed resource management. The framework is expected to offer substantial improvements in response times, network efficiency, and overall user satisfaction compared to traditional cloud-based approaches. However, practical implementation will involve addressing several challenges, including the distributed management of fog nodes, ensuring system scalability, and securing the distributed infrastructure against potential vulnerabilities. Future work will focus on deploying the framework in real-world scenarios to evaluate its practical performance and feasibility.

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