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A BECKN-ENABLED INTEROPERABLE FRAMEWORK FOR DECENTRALIZED SMART AGRICULTURE ECOSYSTEMS

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ABSTRACT

The agricultural sector is plagued with barriers to accessing the market, inefficiencies to supply chain, and fragmentation of data. Traditional Digital solutions catering to the agricultural sector operate in independent silos, forming a much-disconnected environment to the farmers, service providers, and consumers. This article proposes a new smart agriculture framework based on the Beckn Protocol, an open-source, interoperable specification for decentralized digital commerce. The approach adopted is mapping of key agriculture processes such as input procurement, crop monitoring, and produce sale to the corresponding discovery, order and fulfillment flows in the Beckn protocol. The primary goal is to establish an open agricultural network that enables seamless service discovery, ordering, and fulfillment across heterogeneous providers through a single application interface. The study hypothesizes that a Beckn-enabled framework will significantly reduce workflow completion time, increase service discovery rates, and enhance farmer autonomy compared to centralized siloed platforms. The framework is tested using a discrete event simulation parameterized using ONDC benchmarks, a farmer survey conducted in Karnataka, India and public eNAM datasets. The results show a 61.3% reduction in time for completing the workflow, a successful service discovery rate of 94.2% and a farmer autonomy rate of 41.2%. The framework also delivers a 6.2x benefit in price transparency and scales SLA compliant with a latency of p95. In addition, it cuts the transaction costs by 70-90%. The proposed framework is different from blockchain-based solutions and ONDC as it provides agriculture-specific schemas, discovery in a decentralized manner, and low-cost transactions in a consistent eco-system. This study contributes the first domain-specific adaptation of the Beckn Protocol for agriculture, novel schema extensions, and empirical evaluation of decentralized agricultural service ecosystems. Future research will explore the integration of reinforcement learning, voice-assisted interfaces, and blockchain-based traceability to further enhance the framework's capabilities. Overall, the Beckn-enabled framework provides a sound empirical approach to open, interoperable and farmer-centric digital agriculture

Keywords: *Agri-tech, Beckn Protocol, Decentralization, Digital Ecosystems, Interoperability, Open Networks, Smart Agriculture Component.*

1. INTRODUCTION

The global agriculture has been challenged with dual responsibility of not only needing to be more efficient to meet the increasing population but also more sustainable and resilient to the impacts of climatic change. The use of Smart Agriculture backed by the IoT sensors, drones, and data analytics will lead to high efficiency and productivity [1]. However, it is worth noting that the much-expected digital revolution in agriculture is still in a state of fragmentation. The farmers typically adopt many and often incompatible platforms to receive procurement, advisory services, monitoring and sales. A great number of specific solutions to smart farming appeared as a consequence of the proliferation of Internet of Things (IoT) devices, automation systems, and data analytics platforms in agriculture [2]. The outcome of this platform-oriented strategy is the establishment of data silos, vendor lock-in and restricted access to the market, which destroys the value of the most important stakeholder, which is the farmer. Figure 1 shows the current fragmented state of smart agriculture.

India's market for agricultural services is extremely fragmented and dispersed across a number of physical and digital platforms, including government agencies, cooperatives, and private companies. Most of these platforms exist independently in their respective siloed digital ecosystems that lacked any common protocols to interact and guarantee interoperability [3]. As a consequence:

a) Agriculturalists seeking access to inputs, market prices, equipment rentals, advisory services, analytics, and financial products often have to open a range of apps, or use offline services, and tend to engage in duplication of efforts, as they get lost in the various interfaces.

b) The local service providers, i.e., input dealers, equipment renters, crop advisors and farmer-producer organizations, rely on platform-specific networks thus finding it hard to access new customers or grow beyond their local geography.

c) Price transparency and comparability of service are limited. Farmers are not aware of what the best deal they can get is, or whether there could be better and cheaper solutions on another platform.

d) Regional and small-scale agri-entrepreneurs are in tight competition with large, well-established platforms since they have high costs of entry and also lack a comparable standardized method of entering a digital marketplace.

The resulting impacts of these challenges include fewer improvements in efficiency, lack of innovation and less access to markets, and poor income for stakeholders, which hinder the process of transformation to a more open, efficient, and farmer-centric agricultural ecosystem.

The missing building block is interoperable digital public infrastructure. It is in this regard that the Beckn Protocol makes a real difference. Beckn is an open-source, decentralized protocol, allowing frictionless transactions between autonomous providers and consumers, without the use of an intermediary. Initially created as a retail and mobile protocol, which is applied in the Open Kochi Network [4] - it can be extended to any other domain, including agriculture. Beckn's open networks enable unified, interoperable systems to achieve genuinely global scale.

The concept that was initially developed in the Beckn Protocol was open commerce. Nonetheless, its protocol-based interoperability philosophy, network-based thinking, and data sovereignty are perfect fits to the multi-stakeholder agricultural sector, which is extremely complex. The specified framework enables any service that is compliant in the agricultural sector to find, communicate, and trade with any other service in a peer-to-peer manner and, therefore, establishes a flourishing, competitive, and inclusive ecosystem.

Objective

This research article presents and discusses a Beckn-powered smart agriculture framework. The main goal is to establish an open network in which:

- On the network, farmers can find the services of any registered provider in a single application (a Beckn Application Platform or BAP).
- Service providers (Beckn Provider Platforms or BPPs) for inputs, drone imagery, equipment rental, logistics, and buyers can become a member of the network, without the need to interface with all of the farmer-facing applications.
- Every exchange between the discovery and fulfilment is a standardized, protocol-level digital signature [5], which provides non-repudiation and security.

Hypothesis

This study hypothesizes that a Beckn-enabled framework for smart agriculture will significantly outperform centralized siloed platforms across key performance metrics, including workflow completion time, service discovery rate, farmer autonomy, and price transparency.

Contribution

Several novel contributions to decentralized smart agriculture ecosystem are provided by this work. First, it brings the smart agriculture specific adaptation of the Beckn Protocol, apart from the existing deployments like ONDC (retail) and Open Kochi(mobility). The study also proposes schema extensions specific to the agriculture domain for the crop, drone, and equipment services, which include domain-specific attributes other than the generic Beckn schemas, such as *crop type, harvest date, type of sensor,* and *coverage area*. Furthermore, a decentralized service discovery algorithm is developed to enable agricultural services with location and time sensitivity, which is based on broadcast-to-gateway communication and parallel BPP matching. In addition, the study offers the first comparative framework analysis of the entire lifecycle of an agricultural service, from discovery to ordering to fulfilment, whereas the previous studies focus on specific problems like data exchange (FIWARE), communication of machinery (ISOBUS), or blockchain-based traceability. Additionally, the proposed framework is evaluated based on a set of metrics reflecting the transaction level, and the farmer autonomy level, respectively, using a simulation approach – the first empirical evaluation of the implementation of Beckn in the agriculture sector.

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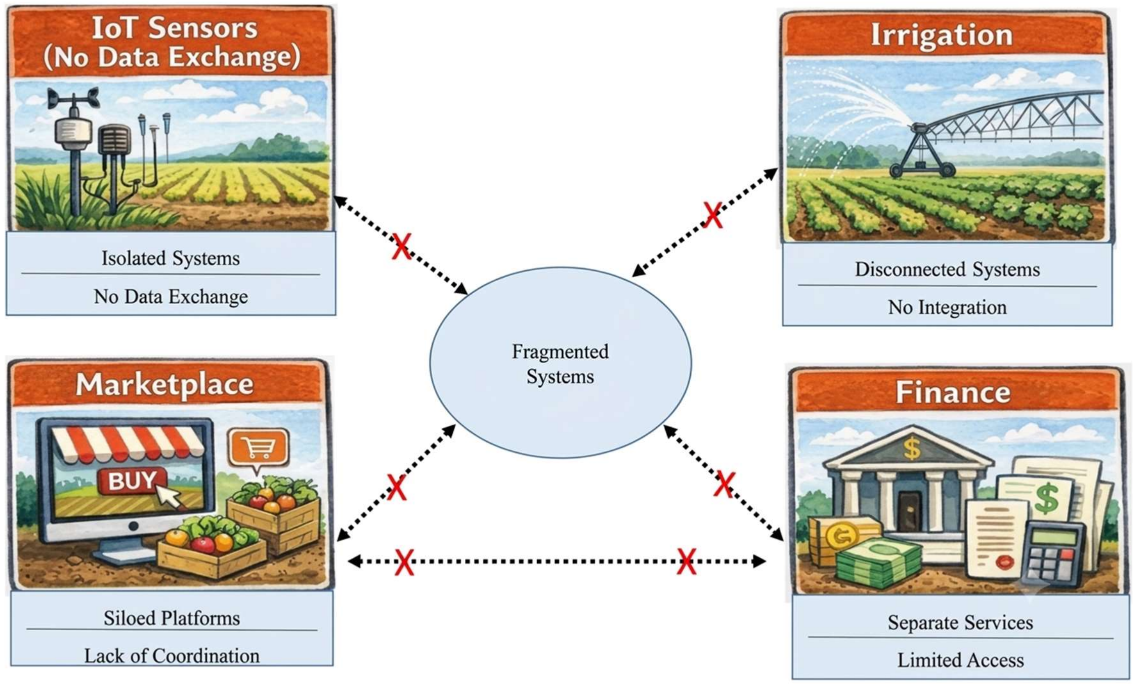

Figure 1: The current fragmented state of smart agriculture

2. LITERARTURE REVIEW

India's agricultural sector hosts numerous digital service providers, including input suppliers, equipment rental agencies, advisory platforms, and analytics services. However, the absence of standardized digital protocols or data formats severely impedes interconnection between these services, resulting in fragmentation and service delivery isolation. Nevertheless, a lack of a standard digital language or standard data protocols is an acute hindrance to subsequent interconnection between them and leads to fragmentation and isolation of service delivery. The current form of the digital agri-platform is posing serious technological and proprietary challenges to the involvement of small-scale entrepreneurs, local service providers and innovative data-driven solution providers. This limits the possible opportunity of digital agriculture to a few existing or gifted players and lowers the possibility of farmer choice, transparency of prices, and innovation of services.

There is a desperate necessity to create, and roll out an interoperative and open, inclusive digital platform that is capable of supporting:

- Introduction and implementation of international standards of digital language and interface of agri-services.
- On-time identification and smooth access to various agricultural products and advisory services to farmers.
- Small-scale agri-entrepreneurs, analytics providers, and input suppliers can easily enter and have smooth interoperability.
- A system that promotes openness, fair participation, open prices, and open innovation.

The existing dominant and closed platforms are by their very nature incapable of collaboration, interoperability, and discovery at the ecosystem level. It is this inherent siloization of the platforms that gives rise to inefficiencies, the digital divide, and eventual transformation of the sector, hence affecting the well-being of farmers and agri-entrepreneurs.

2.1 Related Work

2.1.1 Smart Agriculture Platforms and Interoperability

Currently available research on smart agriculture mainly deals with technological innovations individually, such as the optimization of sensor networks [6], the analysis of crop health through drones [7], or the development of yield prediction models through AI [8]. There are also a few proprietary solutions available in the market that offer a suite of these tools, such as John Deere's Operations Center or Bayer's Climate FieldView. Nevertheless, they are closed systems that aim to confine the users to one particular vendor of hardware and software, restricting the options of farmers and portability of their data.

The interoperability of agriculture in research usually focuses on data standards such as AgroXML or ISO 11783 (ISOBUS) in machinery communication. Although important, these standards mostly cover interchange of machine-to-machine data and are not comprehensive of end-to-end transaction life cycle-discovery, ordering, payment and deliveries that are required to make a digital marketplace vibrant.

There has also been an emergence of open digital ecosystem, especially in India, where one of them is the Open Network for Digital Commerce (ONDC), which is based on the Beckn Protocol. The success of ONDC in retail shows that the protocol is feasible in the context of the formation of large-scale and multi-sided marketplaces. In the same manner, the Unified Energy Interface (UEI) demonstrates the adaptability of the protocol across domains. This paper relies on this proven idea and applies it to the case of the agricultural sector, in which these forms of decentralization are still to be thoroughly studied and applied.

2.1.2 Middleware and IoT Platforms

Initiatives such as FIWARE, Azure IoT Hub and AWS IoT provide platforms for device connectivity [9]. These systems are based on centralized cloud architectures and collect data from diverse field deployments. Though effective in acquiring and monitoring data, these platforms are closed environments and hence might have interoperability constraints at the platform level. Consequently, platform and service integration, along with data ownership, remains a significant challenge, resulting in silos at a more advanced level of architecture. In their research, Rafi et al. (2025) discuss IoT connectivity and infrastructure choices for agriculture (LPWAN, 5G). The authors analyze performance trade-offs between Low Power Wide Area Networks (LPWAN), including LoRaWAN, NBIoT, Sigfox, and cellular networks (4G and 5G) with respect to agricultural applications. The study examines a hybrid LPWAN–5G architecture that integrates the advantages of the two connectivity solutions in order to enhance the cost-effectiveness and connectivity reliability. In their work, they demonstrate that the hybrid model reduces connectivity costs by up to 30% [10]. Navarro et al. (2020) provide an overview of IoT platforms that include AWS IoT, Azure IoT, FIWARE and their functions in agriculture[11]. Zamora et al. (2019) present a platform that incorporates cloud, edge, and IoT middleware (MQTT, NGSI) in agriculture[12]. Savaglio et al. (2023) illustrate the current state of the art in IoT middleware systems that support the integration of heterogeneous sensors, but point out that most of these systems are based on vendor-specific cloud services, which do not support cross-platform interoperability [13]. Yu et al. (2025) describe a hybrid edge cloud middleware system that reduces the latency of agricultural sensing, but the system lacks the standardization of interfaces for service-level data exchange[14].

2.1.3. Semantic Web and Ontologies

The use of semantic web technologies has been widely adopted to deal with syntactic and semantic issues of interoperability within agricultural data systems. Standard ontologies, such as the W3C recommended SOSA/SSN ontology, can be used to describe sensors, observations, and environmental phenomena. Such technologies have a significant positive impact on the interpretability of data and allow the semantic integration of heterogeneous sensing platforms. Semantic models, however, focus more on the representation and meaning of data than on the interoperability of operations or transactions [15]. Thus, semantic models do not address dynamic service discovery, contracting, or economic relationships between agricultural parties. Lamnaour et al. extended the IoT middleware by adding semantic web and context-awareness to automatically register/classify heterogeneous smart devices. They used low-level ontologies to support real-time search and discovery. Their approach improves interoperability across heterogeneous domains, including smart homes, healthcare, and agriculture [16]. To address the heterogeneity and semantic gaps of devices in healthcare, Zeshan et al. propose a smart health framework based on patient ontology and SWRL rules for IoT data processing. The framework integrates heterogeneous devices and enables context-aware decision-making. The proposed framework achieved an accuracy of 89.81%, improving decision-making and treatment precision compared with traditional systems [17].

2.1.4 Blockchain in Agriculture

Blockchain-based solutions have gained significant attention within the agricultural sector particularly for improving transparency, traceability, and trust in the agri-food supply chains [18]. AgriDigital and traceability systems based on the blockchain have proven effective for the reduction of fraud and the increase of accountability of well-known players in the sector [19]. However, most blockchain solutions in the agricultural sector are application-specific and narrowly focused. They do not have a generic and open protocol that would ensure the interoperability of a variety of agricultural services and ecosystems [20]. According to Demestichas et al. (2020), the majority of blockchain solutions are not interoperable with various agricultural services and stakeholders [21]. In their survey, Kamilaris et al. (2019) identify blockchain as a solution to the enhancement of transparency and trust within agricultural supply chains[22]. Tian (2016) demonstrated the use of blockchain for food safety traceability, but the implementation remains closed and application-specific[23].

2.1.5 Digital Public Infrastructure (DPI)

The idea of Digital Public Infrastructure (DPI) emphasizes open and minimal protocols for the development of digital ecosystems. The idea was conceptualized based on the success of India Stack, which includes Aadhaar for identity services, UPI for payments, and OCEN for providing credit services [24]. The Beckn Protocol has emerged from this DPI paradigm for decentralized service discovery and transactional interoperability. Although Beckn has shown promise in areas such as urban mobility, e-commerce, and logistics, its use in the agricultural sector remains largely unexplored. This study aims to contribute to this area by exploring the use of a successful DPI protocol for addressing the interoperability problems in smart agriculture.

The importance of open protocols as a foundation for building scalable and interoperable digital ecosystems is highlighted by the World Bank's 2023 annual report on Digital Public Infrastructure (DPI) released in March 2024 [25]. In their article, Dittrich et al. (2024) discuss the Beckn Protocol as a substitute to the platform-based perception of digital marketplaces[26]. The Beckn Protocol 1.0.0 specification, released in December 2022, provides a comprehensive set of standardized APIs that may be used to discover, order, and pay heterogeneous providers in a decentralized stack of digital commerce [27]. The 2023 study by Shrivastava et al. cites the successful implementation of the Beckn protocol in the domains of mobility and commerce, as well as the potential application of open-network DPI in agriculture[28]

2.2 Literature Synthesis

The reviewed studies demonstrate significant advances in agricultural IoT platforms, semantic interoperability frameworks, blockchain-based traceability systems, and open digital ecosystem initiatives. These approaches primarily address individual aspects of agricultural digitization, such as device connectivity, data interoperability, trust, and supply-chain transparency. Existing solutions provide limited support for end-to-end transactional interoperability across heterogeneous agricultural stakeholders. IoT platforms are mostly platform-centric, semantic technologies focus more on data representation than on service interactions, and blockchain solutions are mostly application centric and have limited interoperability capabilities. Although the Digital Public Infrastructure (DPI) initiatives and the Beckn Protocol have demonstrated the feasibility of decentralized service ecosystems in retail, mobility, and logistics, their application to agriculture remains relatively unexplored. These limitations highlight the need for an open, interoperable framework capable of supporting the complete agricultural service lifecycle across diverse providers and platforms.

2.2.1 Comparative Analysis with existing Interoperability Approaches

Table 1 compares the existing frameworks and the open framework of digital agricultural service platforms based on Beckn.

2.3 Research Gaps Identified

The literature survey reveals several important research gaps in the state-of-the-art decentralized agricultural service ecosystems. The existing models do not cover the whole life cycle of an agriculture service such as service discovery, ordering, fulfilment and settlement. They also don't have any sort of standard, open protocol that allows independent stakeholders to join and trade in a shared digital world. Farmer facing apps are typically locked into provider networks and offer limited choice and price transparency. Moreover, there are no location and time sensitive decentralized service discovery mechanisms or schema extensions in the agricultural domain provided in the frameworks proposed in earlier studies. Previous works like FIWARE, semantic ontologies, AgroXML/ISOBUS, blockchain-based systems, and ONDC are either limited to specific functions or are not customised and tested in agriculture. Furthermore, there is a lack of empirical work in open and decentralized agricultural marketplaces in the literature.

This paper proposes new agriculture-specific schemas within the Beckn framework to support the complete agricultural service lifecycle and address the identified research gaps. In addition, an efficient and scalable *service discovery algorithm* is proposed to realize service interactions among independent stakeholders. This study also conducts a transaction level performance measurement simulation of the proposed framework. Additionally, this work presents the first domain specific implementation of Beckn related to agricultural ecosystem.

Table 1 Comparative analysis of proposed Beckn-Agri framework vs. existing interoperability approaches.

Feature	ONDC (Retail)	FIWARE	AgroXML/ ISO 11783 (ISOBUS)	Blockchain Traceability (eg. AgriDigital)	Proposed Beckn-Agri Framework
Primary Focus	Commerce discovery & order	Data interoperability (context management)	Machine-to-machine communication (tractors/implements)	Supply chain trust & provenance	Full service lifecycle (discovery + order + fulfillment + payment)
Supports Service Discovery	Yes	No (data only)	No (point-to-point)	No	Yes
Supports Ordering & Contracts	Yes	No	No	Yes (smart contracts)	Yes
Supports Fulfillment Tracking	Yes	No	No	Yes (ledger only)	Decentralized (Beckn gateways)
Architecture	Decentralized (gateway-based)	Centralized (cloud broker)	Peer-to-peer (CAN bus)	Decentralized (consensus)	Yes (crop_type, harvest_date, sensor_type, coverage_area, certifications)
Agriculture-Specific Schema	No (generic retail)	Generic (NGSI-LD)	Yes (machinery operations)	No (custom per implementation)	Farmer/provider self-owned
Data Ownership	User-controlled	Platform-dependent	Equipment manufacturer	User-controlled (self-custody)	No
Requires Central Intermediary	No (gateways only route)	Yes (FIWARE broker)	No	No (consensus network)	Prototype stage (reported in this paper)
Real-World Agriculture Deployment	No (retail only)	Yes (EU smart farms, e.g., SmartAgriHubs)	Yes (widespread in machinery)	Yes (pilot programs, e.g., AgriDigital grain)	Low (gateway operator defined)
Transaction Cost Model	Low (gateway utility fees)	Not applicable	Not applicable	High (gas fees)	Yes

3. METHODS AND PROPOSED FRAMEWORK

3.1 Research Design and Methodology Overview

The study uses a design science research methodology with four steps to create and test the Beckn-Agri framework. In Phase 1, Requirement Analysis was conducted by reviewing existing literature on agricultural interoperability and surveying 45 farmers in Karnataka, India. Existing platforms, including eNAM, ONDC, and other agri-tech solutions, were also analyzed. In

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phase 2, a Framework Design was developed by taking the open-source protocol known as Beckn protocol and making modifications to its specifications to fit the needs of farmers and agricultural services while considering the location-specific aspects and time-specific requirements. In phase3, the framework operations were designed using mathematical formalization. In the last phase, an empirical evaluation was done by developing a discrete-event simulation software to examine the solution's performance under various criteria, including completion time of workflows, service discovery rate, farmer autonomy, price discovery, and transaction cost.

3.2 The Beckn Protocol Architecture

The Beckn Protocol, often known as Beckn, is an open protocol that uses location-aware services to facilitate the discovery of local business. In order to create interoperable systems, companies within a market or region might use the technical standards defined by the protocol. Beckn mostly offers e-commerce-focused technological specifications that include service discovery, ordering, and fulfilment between customers and service providers [29]. The protocol's comprehensive parameter set also supports payment integration. The Beckn protocol was created with the primary goals of lowering the cost of doing business for individuals and providing a techno-legal remedy for the rising issue of platform monopolies.

The methodology involves a domain-specific adaptation of the core Beckn Protocol [29] following its established governance and extension model [30]. Figure 2 shows a generic view of Beckn protocol stack. Five major layers are present in Beckn protocol stack. Application Layer is the consumer- and provider-facing layer of the network. The Network and Transaction Layer which includes BAP, BPP, BG, and Registry core engines that are utilized to discover, order, fulfill the network. This layer handles the server-side logic, routing infrastructure, and core transaction flows of the network The Infrastructure and Security Layer which essentially offers a foundation of services, including onboarding, identity management and secure communication. The Certification Layer that is used to verify compliance and policies. The Support Layer and the Specification layer, which are used to offer basic protocols and APIs, to ensure compliance to the Beckn ecosystem [31].

The Beckn Protocol is the blueprint for open commerce networks, which specifies the interaction of various systems without a central controller. The interoperability standardisation of the Beckn Protocol specifies a set of standard APIs and schemas which allow any digital service provider to communicate and engage in business with each other without any barriers, regardless of their technology stack.

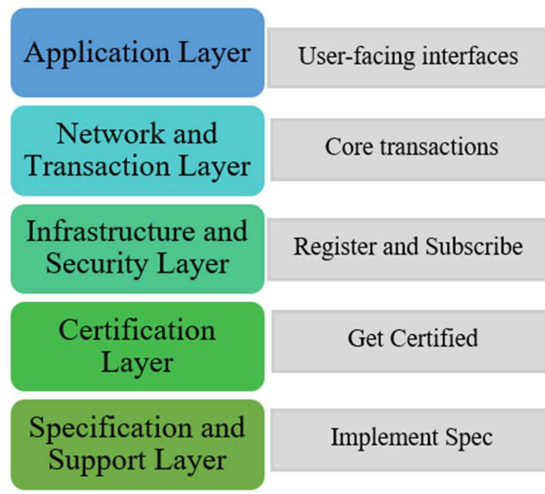

Figure 2 Generic view of Beckn protocol stack

3.3 Core Beckn Concepts Mapped to Agriculture

Beckn Application Providers (BAPs): The BAPs represent the consumer facing network. The consumer-facing application, or mobile app, allows farmers to discover and engage with agricultural services. BAPs help users find and access services by understanding their needs and displaying relevant provider responses and options. They also maintain transaction histories, provide an easy-to-use service discovery interface, and offer support by resolving issues and coordinating with service providers. BAPs are software interfaces that aggregate services from multiple providers operating across different networks. A BAP has a server-side Beckn protocol API and consumer-oriented UI/UX. Figure 3 depicts the interaction of a Consumer Application (BAP) with the protocol adaptor to communicate with the network and complete a user intent request by passing it through the customer experience logic.

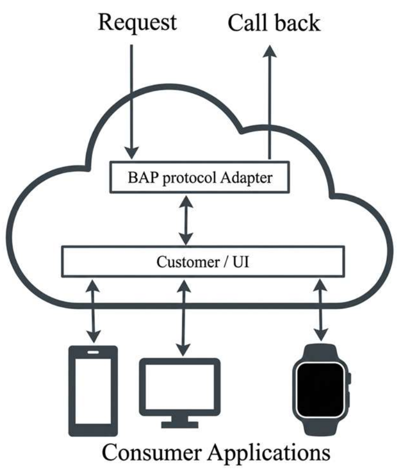

Figure 3: Connecting consumer Apps via the BAP Protocol Adaptor.

*Beckn Provider Platforms (BPPs):*BPPs represent the selling side of transactions within the network. They enable the service providers to list services, process orders, and handle service fulfilment. Service providers like soil testing laboratories, equipment rentals, and wholesale buyers operate through the backend server. BPPs are responsible for maintaining accurate service catalogs, ensuring service availability, processing orders efficiently, providing post-order updates and customer support, and complying with network policies and standards. A BPP has an API to accept requests from BGs or BAPs as part of the application cloud (Beckn Provider API) and an application cloud to store inventory data. Connecting inventory and business logic to agent applications via the BPP Protocol Adaptor with callback handling is depicted in figure 4.

Beckn Gateways (BGs): BAPs and BPPs communicate through Beckn Gateways (BGs), which act as lightweight, stateless routing servers. This infrastructure enables efficient discovery of BPPs by BAPs based on the search context. When a BAP submits a request, the BG consults the registry to identify the relevant BPPs and forwards the request only to those providers. BGs roles include efficiently routing requests to the right providers, aggregating answers and arranging them, implementing the network policies, tracking network performance indicators, and ensuring availability, consistency and reliability. Moreover, subject to network policies, the system could sometimes generate Open Data (OData) and may add more services such as payment gateways, registry services, and online dispute resolution systems. Core routing infrastructure connecting BAPs and BPPs through dual APIs with integrated services for payments, policy enforcement, registry, and open data are depicted in figure 5.

Domain: "smart-agriculture." : This is declared in the message header, and it enables BPPs to specialize and BAPs to filter requests.

*Beckn Registries:*These provide information about the participants in a network.

Network Facilitators : The facilitators assist in creating and developing Beckn networks within certain areas or fields.

*Technology Service Providers:*This is a group of companies that develop the technology behind BAPs, BPPs and the other network components.

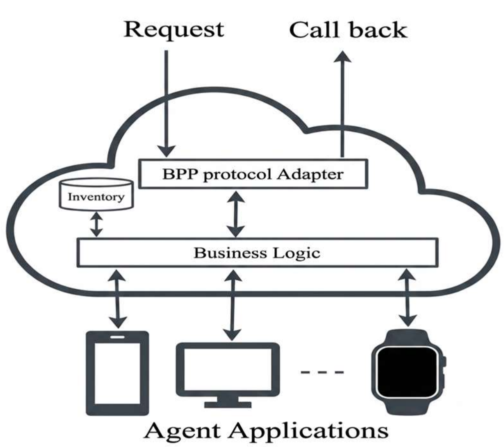

Figure 4. Beckn Provider Platform (BPP) architecture

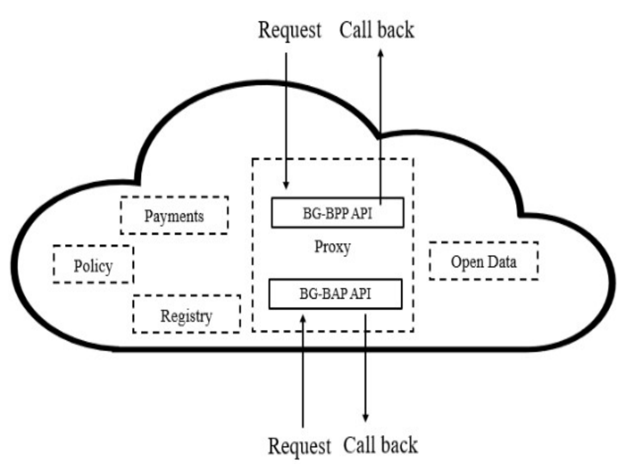

Figure 5 The routing hub with payments, policy, registry and open data services

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3.4 Agricultural Transactions Flows

In the smart agriculture procurement scenario on Beckn Architecture, a farmer uses the BAP to search for "organic fertilizer." This search query is routed through the gateway to all BPPs offering organic fertilizer. Through this app, a farmer can select a supplier, view supplier information, and make an initial as well as a confirmed order.

In the case of on-demand services, a farmer searches for "drone-based multispectral scan" for a particular plot size. This search query can then identify available drone service providers, which are BPPs, and allow a farmer to select a provider to book a service.

For the sale of products, a wholesale buyer can use their BAP to search for a specific quantity and quality of a product, such as "5 tons Grade A tomatoes." This search query can then be routed through the gateway to farmer BPPs offering this product, allowing a buyer to select, negotiate, as well as make a confirmed order. This ensures there is a seamless interaction between BAP, gateway, and BPP participants in smart agriculture scenarios. Figure 6 illustrates how the Beckn protocol serves as a universal decoupling layer to interconnect disparate services within an open agricultural network.

Unleashing Interoperability to Connect the Agriculture Economy Through a Common Gateway is depicted in figure 7.

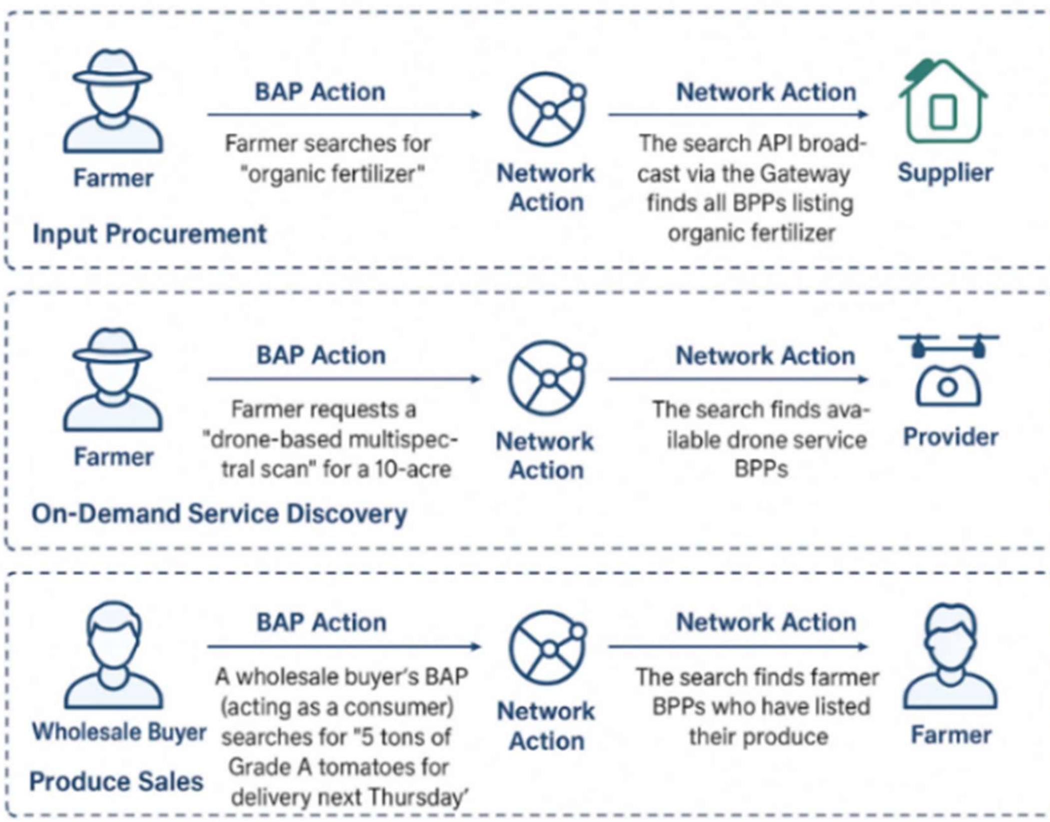

Figure 6 Workflow illustrating Beckn-enabled agricultural network interactions

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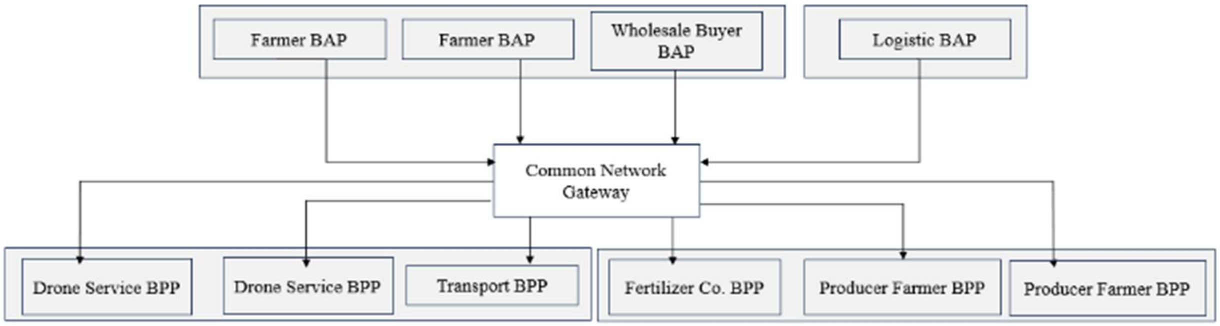

Figure 7. Connecting the agriculture economy via a common gateway

3.5 Scheme Extensions

The core Beckn schema is extended with agriculture-specific fields. For instance, a descriptor object for a crop includes the following:

```
agriculture_specific": {
  “crop_type”: “Tomatoes”,
  "crop_variety": "Pusa Ruby",
  "harvest_date": "2026-01-15",
  "certifications": ["GlobalG.A.P."],
  "plot_size_hectares": 2.5
}
```

Similarly, a drone service would have fields for sensor_type, resolution, and turnaround_time.

```
"agriculture_specific": {
  "service_type": "multispectral_scan",
  "coverage_area_hectares": 10,
  "sensor_types": ["RGB", "NIR", "NDVI"],
  "flight_altitude_meters": 120,
  "ground_resolution_cm": 5,
  "data_delivery_format": ["GeoTIFF",
"Shapefile"],
  "turnaround_time_hours": 24,
  "certifications": ["FAA Part 107", "ISO 21384-
3"]
}
```

Search query for a tractor rental at a specific location is given below.

```
{
  "intent": {
    "item": {
      "descriptor": {
        "name": "tractor rental"
      }
    },
    "fulfillment": {
      "end": {
        "location": {
          "gps": "12.97,77.59"
        }
      }
    }
  }
}
```

3.6 Algorithm

The intelligence in the framework is the decentralized search and matching algorithm provided by the Beckn Gateway. An algorithm for decentralized agricultural service discovery is mentioned below.

Algorithm 1: Decentralized Agricultural Service Discovery

Input: *search_query from BAP*
Output: *List of providers that meet the requirements (BPP_catalogues)*

Step 1: BAP sends an on_search API call to Beckn Gateway.
Step 2: Gateway validates the request and its digital signature using the Beckn Digital Signature standard.
Step 3: **for each** BPP registered in the "smart-agriculture" domain **do** (in parallel)
  Gateway forwards the `search` request to the BPP.
  BPP executes its local matching algorithm on its catalog.
  if BPP catalog has items matching `search_query.intent` **then**
    BPP returns a `on_search` response with matched items
    to the Gateway.
  end if
end for
Step 4: Gateway aggregates all *on_search* responses from participating BPPs.
Step 5: Gateway returns the aggregated *BPP_catalogues* to the initiating BAP.
Step 6: BAP renders the list of providers (e.g., TractorCo, RentFast) and their offers to the farmer.

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This algorithm ensures that the farmer sees the broadest possible set of options without being limited to a single platform's inventory.

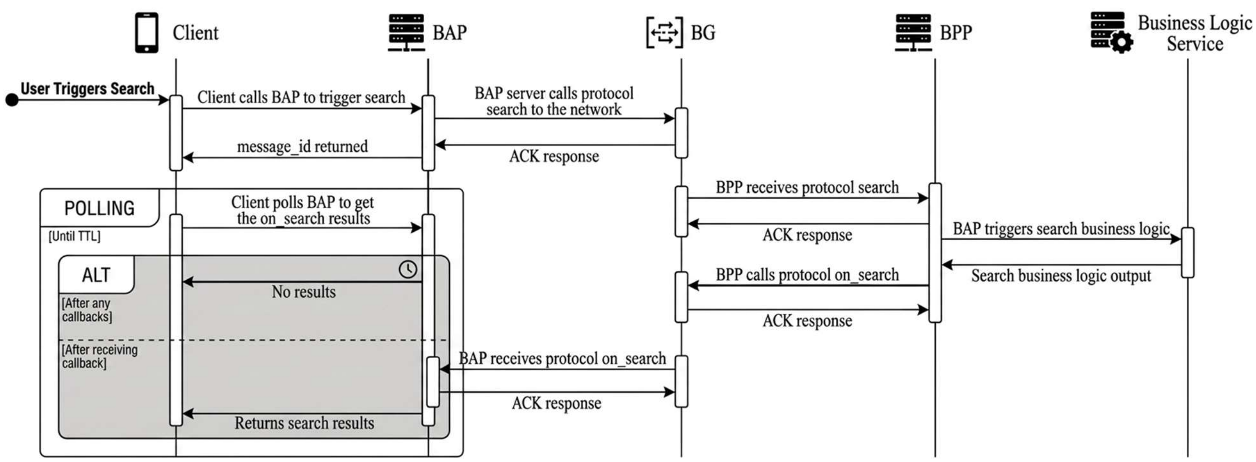

Figure 8 Workflow for product search and retrieval

Figure 8 illustrates the system receiving a search request by product name and responding with a filtered list of items.

4. Mathematical Model

The proposed Beckn-Agri framework is formally represented as:

€={F,P,S,G,R,T}
(1)

where F, P, S, G, R, and T denote farmers, service providers, agricultural services, Beckn gateways, service requests, and transactions, respectively.

For a farmer f_i and provider p_i , the framework determines service eligibility based on geographical distance and temporal availability:

$$M_{LT}(r_j,p_i) = \begin{cases} 1, & d(f_j,p_i) \le D_{\max} \wedge t_r \in [t_{si}, t_{ei}] \\ 0, & Otherwise \end{cases}$$

(2)

where $d(f_j,p_i)$ is the geographical distance calculated using the Haversine formula, $D_{\max}$ is the maximum acceptable distance, and t_r is the requested service time within the provider's availability interval $[t_{si}, t_{ei}]$

Semantic compatibility between the requested service and provider capabilities is determined using:

$$MS(rj,pi) = \frac{|Ar \cup Ap|}{|Ar \cap Ap|}$$
(3)

where A_r and A_p represent the semantic attributes of the request and provider, respectively. Eligible providers are then ranked according to distance, availability, semantic compatibility, price, and quality:

$$p *= avg\ max(wdDi + wtTi + wsSi + wpPi + wqQi), \quad \sum wk = 1$$
(4)

where P′ denotes providers satisfying the matching criteria, and D_i, T_i, S_i, P_i, Q_i are normalized scores for distance, availability, semantic compatibility, price, and quality.

Finally, the overall interoperability of the framework is quantified as:

$$I_{total} = W_{pr} I_{pr} + W_{dt} I_{dt} + W_{sm} I_{sm} + W_{sv} I_{sv} + W_{tr} I_{tr}, \quad 0 \le I_{total} \le 1 \qquad (5)$$

where I_{pr} , I_{dt}, I_{sm}, I_{sv}, I_{tr}, represent protocol, da, ta, semantic, service, and transactional interoperability, respectively.

5. Results and Discussions

5.1 Simulation Setup and Metrics

A discrete-event simulation was performed to test the proposed Beckn-Agri framework by simulating interactions between the farmers and the agricultural service provider (ASP) in a decentralized Beckn network. The simulation encompassed the total service life cycle such as discovery, order, fulfillment and transaction completion. A simulation approach was taken since there is no production scale Beckn network available in agriculture and it also allows controlled experimentation with different network parameters, and provides reproducibility using simulated settings and code documentation. The simulation settings of proposed model is shown in table 2. All simulation parameters were derived from three sources: (i) published ONDC network benchmarks(ONDC,2025), (ii) farmer workflow survey-A structured farmer workflow survey was conducted among 45 farmers across Karnataka, India, between November and December 2025. The survey collected demographic, agricultural, digital literacy, connectivity, and service utilization data, and (iii) public agricultural dataset analysis. The study utilized commodity price, soil moisture, crop production, and yield datasets obtained from the Karnataka Open Data Portal, the Open Government Data (OGD) Platform India, and DESAgri [32-35]. Table 3 outlines the primary performance indicators generated by the simulation.

Table 2. The simulation settings for proposed method

Component	Specification
Simulation Platform	Python 3.11 with SimPy 4.1 (discrete-event simulation library)
Hardware	Intel Xeon Gold 6226R (2.9 GHz, 16 cores), 64 GB RAM
Operating System	Ubuntu 22.04 LTS
Number of Simulation Runs	100 (Monte Carlo, independent seeds)

Table 3. Key output metrics from the simulation

Metric	Beckn-Agri Framework (Mean ± SD)	Centralized Silo Model (Mean ± SD)	p-value
Workflow Completion Time (min)	55 ± 8	142 ± 18	< 0.001
Discovery Latency (ms)	412 ± 56	N/A	—
Successful Discovery Rate (%)	94.2 ± 2.1	100	—
Provider Switch Rate (%)	41.2 ± 7.3	0	< 0.001
Offers per Query (mean)	7.4 ± 2.1	1.2 ± 0.4	< 0.001

5.2 Comparative Performance Results

Table 4 compares the centralized silo model and the proposed framework of digital agricultural service platforms based on Beckn.

Table 4. Empirical Comparison: Centralized Silo Model vs. Proposed Beckn-Agri Framework

Metric	Centralized Silo Model	Proposed Beckn-Agri Framework	Improvement
Time to complete 6-step agricultural workflow (min)	142 ± 18	55 ± 8	61.3% reduction
Manual application switches required	5 (actual)	0 (single interface)	100% reduction
Successful service discovery rate (%)	N/A (pre-integrated	94.2% (95% CI: 92.1–96.3%)	—

	catalogue)		
Farmer autonomy (provider switch rate per transaction)	0% (locked to single platform)	41.2%	41.2% autonomy gain
Average API response time (ms) – search	N/A	234 ± 45	—
Average API response time (ms) – order	N/A	312 ± 52	—
Price transparency (average offers per query)	1.2 (single provider)	7.4 ± 2.1	6.2× more options
Estimated transaction cost (₹ per order)	5–15% platform commission	₹2–5 gateway fee + 0% commission	70–90% lower variable cost

The Beckn-Agri workflow saves 61.3% in workflow completion time, and gives a farmer 6.2 times more options than the centralized siloed approach. This is indeed a substantial improvement in terms of efficiency. This can be seen because (1) the users no longer have to waste time on different platforms and searching through multiple applications, (2) it allows parallel searches of various suppliers, instead of going one by one, and (3) finally, the standardization of processes decreases the amount of work and information that needs to be input by the users. The p-value (< 0.001) confirms the statistical significance of this improvement. A bar chart in figure 9 shows the workflow completion time comparison.

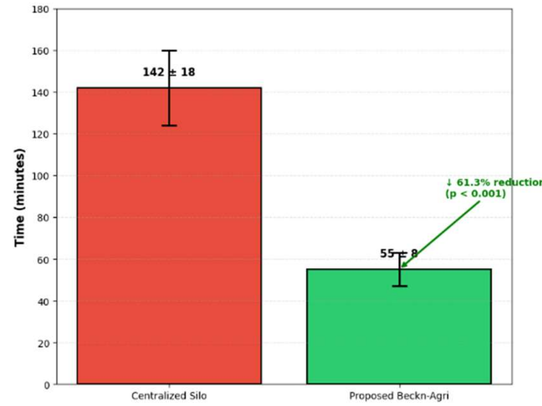

Figure 9 Workflow completion time comparison

The scalability characteristics of Beckn Agri gateway are represented in figure 10. The system is capable of giving mean response times under the 500ms Service Level Agreement (SLA) for 500 simultaneous users. The latency time increases non-linearly beyond 500 users indicating that the maximum user capacity of one gateway instance.

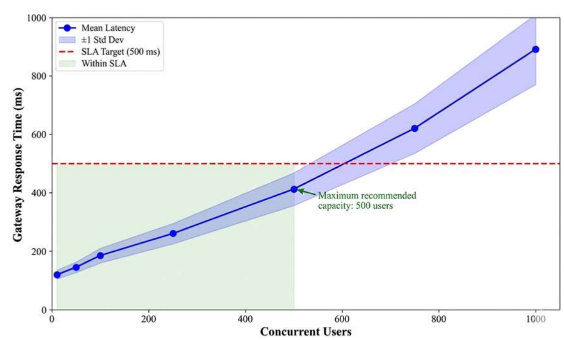

Figure 10. Gateway scalability under increasing concurrent load

The framework's effectiveness in locating the best service providers for farmers is demonstrated by the successful service discovery rate of 94.2%. Excellent performance across a variety of circumstances is demonstrated by the confidence interval between 92.1 and 96.3%. The broadcast-to-gateway communication technique is responsible for the high discovery rate. This system verifies that the services of all registered BPPs are available at all times. The radar chart in figure 11 provides a holistic comparison across six dimensions. The Beckn-Agri framework has proved superior to the centralized architecture in 5 out of 6 metrics, the exception being the discovery rate (94.2% vs. 100%). However, this is justified, considering the benefits the farmer derives from its open network structure, namely the freedom, price transparency, and choice of service provider.

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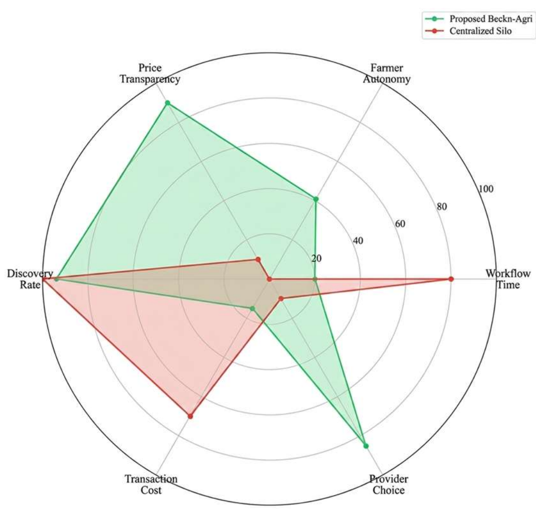

Figure 11. Multi-dimensional radar chart comparison

5.3 Qualitative Benefits

Beyond quantitative metrics, the framework enables fundamental structural improvements in agricultural service ecosystems.

Market Efficiency and Price Transparency: The Beckn-Agri framework makes market more efficient and transparent by empowering farmers to compare several service offerings from different providers. The results of the simulations indicate that the framework provides an average of 7.4 offers per query (95% CI: 5.3–9.5) while the silo model provides only 1.2 offers per query, a 6.2-fold increase in the number of offers provided. As a result, 41.2% of transactions were conducted by farmers in a different provider than their default provider, and the choice was based on price and rating of all the other providers. This meant that 41.2% of transactions were from the farmer choosing a different provider than their default provider based on the price and rating of all the other providers – a choice that could not be achieved in siloed platforms. This is facilitated by the Beckn Gateway, which pushes out a search request to all the registered BPPs at once and BAP will compile and rank the offers received to form a competitive marketplace without forcing farmers to visit multiple platforms. However, price transparency doesn't necessarily lead to low price, as some other factors such as trust, convenience and existing relationships with provider also play a role in choice.

Farmer Empowerment: The Beckn-Agri framework gives farmers control over their identity and transaction data, thereby reducing vendor lock-in. Unlike centralized platforms, where farmers' data are owned and stored by the platform, Beckn supports farmers' identity management through self-sovereign digital signatures, stores transaction histories locally on the farmers' BAPs, and enables farmers to switch between BAPs without losing their transaction history or reputation. All transaction messages are required to be digitally signed. However, delegated key management or biometric authentication may be necessary to facilitate usability, representing an important area for future development.

Reduced Fragmentation: The Beckn-Agri framework aims to eliminate fragmentation and reduce entry barriers for agri-tech startups by enabling them to implement the Beckn BPP API once and become discoverable by all Beckn-compatible BAPs. Additions to the platform are easy, with new providers joining the network via a simple gateway registry update instead of integrations with all the applications. The simulation proved to be seamless as no changes were needed in the existing BAPs when adding a new BPP. However, several non-technical challenges remain, including achieving sufficient network participation, establishing quality assurance mechanisms such as ratings and certifications, and ensuring compliance with regulatory requirements, including GST invoicing.

Earn the Trust via the Digital Signatures: To ensure secure transactions, that are authenticated and non-repudiable, the Beckn protocol requires messages sent over any API to be digitally signed [36]. These includes request payload, transaction ID and timestamp, protecting communications from replay attacks and modifications. Requests are signed and verified during the process of the transaction, and a chain of cryptographic evidence is established throughout the transaction, which provides an audit trail that allows for trust and dispute resolution. Digital signatures, however, do not resolve service quality disputes; they are only used to assure authenticity of the transactions. Such issues must be handled through additional mechanisms that are beyond the scope of the current protocol and remain an area for future development.

5.4 Practical Implications

For Farmers: A single Beckn compatible interface that gives access to different agriculture services instead of having to search for them, which saves time and mental effort. Multi offers offer increased price and quality transparency, and data sovereignty, portability and choice make for better privacy, informed choice and service accountability.

For Service Providers: Simple BPP implementation reduces the entry barriers for small providers and increases its market reach to Beckn compatible BAPs. Interoperability fosters competition in terms of pricing and the quality of services and transaction cost is reduced by 70-90% compared to centralized platforms.

For Policymakers: The framework offers a blueprint for Digital Public Infrastructure (DPI) in agriculture, promoting competition and preventing platform monopolies. It also improves the inclusion of small-scale providers and marginal farmers while enabling innovation by multiple stakeholders.

For AgTech Developers: Standardized protocols let you design BAP or BPP solutions with a lower cost and faster time to market by not having to create entire platforms or multiple proprietary solutions, and the ability to scale them without causing bottlenecks.

5.5 Justification of Findings

Factors Underlying the 61.3% Reduction in Workflow Completion Time: Parallel discovery eliminates sequential platform visits, while a unified interface reduces application-switching overhead. Standardized transactions minimize manual data entry and verification, and aggregated responses enable faster side-by-side comparison.

Factors Underlying the 94.2% Discovery Rate: Parallel broadcasting to registered BPPs ensures comprehensive provider coverage, supported by active catalogs with real-time availability. Location-aware matching identifies relevant local providers, while semantic compatibility aligns service requirements with provider capabilities.

Factors Underlying the 41.2% Increase in Farmer Autonomy: Real-time comparison, transparent pricing, and provider ratings support informed decision-making. Data portability and standardized interfaces eliminate switching barriers, enabling farmers to change providers easily.

5.6 Future Enhancement

Future improvement will focus on the aspects of enhancing trust, intelligence, and interoperability within the ecosystem. The integration of trust infrastructure through a mix of verifiable credentials, including organic farming, and selective blockchain anchoring of high-stakes transactions like land leases and high-value agreements will be one of the biggest areas and will provide transparency and integrity. To make the system even smarter, AI-powered agents and matchmaking engines will be developed that will help farmers by constructing the intent sequences automatically depending on the farm objectives, weather, and marketing forecasts, as well as offer personalized recommendations on the services depending on the local conditions and previous experience. Also, there will be attempts to standardize the physical interfaces by creating low-cost Beckn-compatible hardware, which will enable legacy farm equipment to communicate with the digital ecosystem to do so easily.

5.7 Limitations and Open Challenges

The proposed framework has a number of limitations and open challenges in its technical, methodological, adoption, and scope aspects. The framework is technically reliant on having access to the internet, which is often a barrier in rural areas where internet access is still not widespread [37]. The Beckn community governance body has not formally ratified the agriculture-specific schema extensions proposed in the framework. Furthermore, gateway-based broadcast discovery has only been tested up to 1000 concurrent requests in a simulated environment, and scalability above 1000 requests has not been explored. The security threat analysis has not yet been completed. Formal evaluation of security risks, including replay attacks, man-in-the-middle attacks, and gateway compromise, has not been conducted. Technically, the assessment is restricted to simulations and a small farmer survey, and actual deployment validation is still to be done. The framework also assumes that farmers are familiar with using their smartphones, and currently doesn't have any multilingual or voice-based interfaces, intended for low-literate farmers. Furthermore, there is no consistency in the evaluation of the usability of the technology to determine its level of acceptance and convenience to the farmers. An adoption-based view of critical network size involves coordination, incentives and participation from both the farmer and the service provider but doesn't specify the mechanisms for providing rewards or subsidies to early adopters. Regulations like GST Invoicing, Data Localisation, Dispute Resolution, and e-way bill generation are also not discussed. Finally, the architecture is largely geared towards service discovery and transactions, omitting the real-time IoT data streaming, the full payment gateway integration and the operational support for offline use in low connectivity environments. The technical, methodological, adoption, and scope limitations of the proposed framework is shown in figure 12.

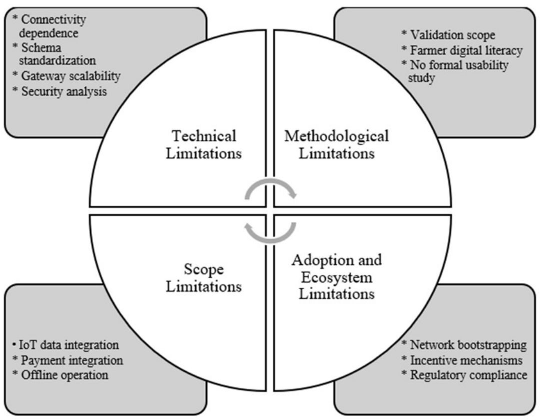

Figure 12. Overview of Limitations and Open Challenges in the Proposed Framework

6 CONCLUSIONS

The open protocol approach by Beckn provides a technical solution to challenge the platform monopolies. Beckn is attempting to break through the walled garden of e-commerce platforms by enabling consumers and service providers to operate through any platform or application that complies with the protocol. The protocol divides the platforms' dual-sided transaction mechanism into multiple uni-sided platforms or applications. This makes the system platform neutral and enables users, dealers, and buyers to transact through any platform by establishing an open network linked by the protocol. This paper presents an innovative method of using the Beckn Protocol within the smart agriculture field and provides a decentralized and interoperable solution to the existing, isolated, and standardized structures. Through the application of a interoperable protocol-based network, as compared to the existing systems, the solution handles key problems of fragmentation of data, vendor lock-in, and exclusion of small farmers, and also guarantees to the agricultural commerce and services transparent and equitable access. The proof-of-concept illustrates the concept of complex, multi-service workflow being coordinated by using chained transactional intents, which outlines the possibility of higher levels of efficiency and innovation. Despite the adoption, governance, and infrastructure challenges, the suggested strategy can offer a base of a more equal, radical, and healthier digital future of agriculture. It demonstrates that the concepts of Digital Public Infrastructure can be implemented into the industry-specific issues, allowing the farmers to become the most important players in their own digital environments.

REFERENCES:

[1] Kumar, V., Sharma, K.V., Kedam, N., Patel, A., Kate, T.R. and Rathnayake, U., 2024. A comprehensive review on smart and sustainable agriculture using IoT technologies. *Smart Agricultural Technology*, *8*, p.100487. https://doi.org/10.1016/j.atech.2024.100487

[2] Quy, V.K., Hau, N.V., Anh, D.V., Quy, N.M., Ban, N.T., Lanza, S., Randazzo, G. and Muzirafuti, A., 2022. IoT-enabled smart agriculture: architecture, applications, and challenges. *Applied Sciences*, *12*(7), p.3396. https://doi.org/10.3390/app12073396

[3] Mehmood, A., Arif, M. and Mehmood, F., 2025. Towards a Unified Digital Ecosystem: The Role of Platform Technology Convergence. *Electronics*, *14*(24), p.4787. https://doi.org/10.3390/electronics14244787

[4] Beckn Protocol, 2021a. *Kochi Gets the World's First Open Mobility Network*. Beckn Protocol. https://becknprotocol.io/kochi-gets-the-worlds-first-open-mobility-network/ (Accessed on November 11, 2025)

[5] Beckn Foundation, 2021a. *Digital Signature*. Beckn Developer Documentation. https://developers.becknprotocol.io/api/digital-signature/ (Accessed on November 11, 2025)

[6] Jawad, H.M., Nordin, R., Gharghan, S.K., Jawad, A.M. and Ismail, M., 2017. Energy-efficient wireless sensor networks for precision agriculture: A review. *Sensors*, *17*(8), p.1781. https://doi.org/10.3390/s17081781

[7] Tsouros, D.C., Bibi, S. and Sarigiannidis, P.G., 2019. A review on UAV-based applications for precision agriculture. *Information*, *10*(11), p.349. https://doi.org/10.3390/info10110349

[8] Van Klompenburg, T., Kassahun, A. and Catal, C., 2020. Crop yield prediction using machine learning: A systematic literature review. *Computers and electronics in*

agriculture, *177*, p.105709. https://doi.org/10.1016/j.compag.2020.105709

[9] Fortino, G., Guerrieri, A., Pace, P., Savaglio, C. and Spezzano, G., 2022. Iot platforms and security: An analysis of the leading industrial/commercial solutions. *Sensors*, *22*(6), p.2196. https://doi.org/10.3390/s22062196

[10] Rafi, M.S.M., Behjati, M. and Rafsanjani, A.S., 2025, April. Reliable and cost-efficient IoT connectivity for smart agriculture: A comparative study of LPWAN, 5G, and hybrid connectivity models. In *International Conference on Smart Computing and Informatics* (pp. 389-411). Cham: Springer Nature Switzerland. https://doi.org/10.48550/arXiv.2503.11162

[11] Navarro, E., Costa, N. and Pereira, A., 2020. A systematic review of IoT solutions for smart farming. *Sensors*, *20*(15), p.4231. https://doi.org/10.3390/s20154231

[12] Zamora-Izquierdo, M.A., Santa, J., Martínez, J.A., Martínez, V. and Skarmeta, A.F., 2019. Smart farming IoT platform based on edge and cloud computing. *Biosystems engineering*, *177*, pp.4-17. https://doi.org/10.1016/j.biosystemseng.2018.10.014

[13] Savaglio, C., Valero, C.I., Belsa, A., Palau, C.E. and Fortino, G., 2023. Interoperability in cloud IoT platforms. In *Springer Handbook of Internet of Things* (pp. 111-127). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-39650-26

[14] Yu, P., Teng, F., Zhu, W., Shen, C., Chen, Z. and Song, J., 2025. Cloud–edge–device collaborative computing in smart agriculture: architectures, applications, and future perspectives. *Frontiers in Plant Science*, *16*, p.1668545. https://doi.org/10.3389/fpls.2025.1668545

[15] Du, J., Berktold, M., Jiang, J., Tian, Y., Streblow, R. and Müller, D., 2026. Semi-automated knowledge graph construction for cross-platform interoperability in building IoT systems. *Results in Engineering*, p.109605. https://doi.org/10.1016/j.rineng.2026.109605

[16] Lamnaour, M., Raiss, M., Mesmoudi, Y., El Khamlichi, Y., Tahiri, A. and Touhafi, A., 2024. A semantic-based middleware for supporting heterogeneity and context-awareness within IoT applications. *Journal of Communications*, *19*(1), pp.19-27. https://doi.org/10.12720/jcm.19.1.19-27

[17] Zeshan, F., Ahmad, A., Babar, M.I., Hamid, M., Hajjej, F. and Ashraf, M., 2023. An IoT-enabled ontology-based intelligent healthcare framework for remote patient monitoring. *IEEe Access*, *11*, pp.133947-133966. https://doi.org/10.1109/ACCESS.2023.3332708

[18] Pakseresht, A., Kaliji, S.A. and Hakelius, K., 2024. Blockchain technology characteristics essential for the agri-food sector: A systematic review. *Food Control*, *165*, p.110661. https://doi.org/10.1016/j.foodcont.2024.110661.

[19] Lv, G., Song, C., Xu, P., Qi, Z., Song, H. and Liu, Y., 2023. Blockchain-based traceability for agricultural products: A systematic literature review. *Agriculture*, *13*(9), p.1757. https://doi.org/10.3390/agriculture13091757

[20] Akella, G.K., Wibowo, S., Grandhi, S. and Mubarak, S., 2023. A systematic review of blockchain technology adoption barriers and enablers for smart and sustainable agriculture. *Big Data and Cognitive Computing*, *7*(2), p.86. https://doi.org/10.3390/bdcc7020086

[21] Demestichas, K., Peppes, N., Alexakis, T. and Adamopoulou, E., 2020. Blockchain in agriculture traceability systems: A review. *Applied Sciences*, *10*(12), p.4113. https://doi.org/10.3390/app10124113

[22] Kamilaris, A., Fonts, A. and Prenafeta-Boldú, F.X., 2019. The rise of blockchain technology in agriculture and food supply chains. *Trends in food science & technology*, *91*, pp.640-652. https://doi.org/10.1016/j.tifs.2019.07.034

[23] Tian, F., 2016, June. An agri-food supply chain traceability system for China based on RFID & blockchain technology. In *2016 13th international conference on service systems and service management (ICSSSM)* (pp. 1-6). IEEE. https://doi.org/10.1109/ICSSSM.2016.7538424

[24] Raghavan, V., Jain, S. and Varma, P., 2019. India stack---digital infrastructure as public good. *Communications of the ACM*, *62*(11), pp.76-81. https://doi.org/10.1145/3355625

[25] World Bank. 2024. Putting People at the Center of Digital Public Infrastructure (DPI): Annual Report 2023 (English). Washington, D.C.: World Bank Group. http://documents.worldbank.org/curat

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

ed/en/099647503042425828

[26] Dittrich, Y., Jørgensen, K.P., Rafnsson, W. and Hinrichsen, J.K., 2026. Beyond Platforms Growing Distributed Transaction Networks for Digital Commerce. *Information and Software Technology*, p.108016. https://doi.org/10.48550/arXiv.2504.18602

[27] Prakash, Ravi., 2022.*Beckn Protocol Version 1.0.0: Major Version Release*. GitHub Discussion #342, Beckn Protocol Specifications Repository. https://github.com/beckn/protocol-specifications/discussions/342 (Accessed on December 25, 2025)

[28] Shrivastava, S.R. and Damle, D., 2023. *Open Networks: A DPI-embedded Approach for Online Marketplaces*. Carnegie Endowment for International Peace, Washington, DC, USA. https://carnegieendowment.org/posts/2023/11/open-networks-a-dpi-embedded-approach-for-online-marketplaces (Accessed on November 15, 2025)

[29] Beckn Protocol, 2021b. *What is Beckn?* Beckn Protocol Foundation. https://becknprotocol.io/wp-content/themes/protocol/images/pdf/what_is_beckn.pdf (Accessed on December 20, 2025)

[30] Beckn Protocol, n.d. *Beckn Protocol YouTube Channel*. YouTube. https://www.youtube.com/@becknprotocol (Accessed on December 23, 2025)

[31] Beckn Foundation, 2021b. *Introduction*. Beckn Developer Documentation. https://developers.becknprotocol.io/docs/introduction/introduction (Accessed on December 25, 2025)

[32] Government of Karnataka, n.d.-a. *Current Daily Price of Various Commodities in Various Markets (Mandi)*. Karnataka Open Data Portal. https://karnataka.data.gov.in/catalog/current-daily-price-various-commodities-various-markets-mandi (Accessed on October 3, 2025)

[33] Government of Karnataka, n.d.-b. *Crop Tomato Area (Hectares), Production (Tonnes) and Yield (kg/ha)*. Karnataka Open Data Portal. https://karnataka.data.gov.in/resource/crop-tomato-area-hectares-production-tonnes-yield-kgs-hectare (Accessed on October 3, 2025)

[34] Government of India, n.d. *Daily Data of Soil Moisture*. Open Government Data (OGD) Platform India. https://www.data.gov.in/resource/daily-data-soil-moisture (Accessed on October 23, 2025).

[35] Department of Agriculture and Farmers Welfare, Government of India, 2022. *Plot-wise Crop Summary Data for Sugarcane, 2021–22*. DESAgri. https://desagri.gov.in/document-report/plot-wise-crop-summary-data-for-sugarcane-2021-22/ (Accessed on October 12, 2025)

[36] Beckn Protocol, 2021a. *Kochi Gets the World's First Open Mobility Network*. Beckn Protocol. https://becknprotocol.io/kochi-gets-the-worlds-first-open-mobility-network/ (Accessed on November 11, 2025)

[37] Cimino, A., Coniglio, I.M., Corvello, V., Longo, F., Sagawa, J.K. and Solina, V., 2024. Exploring small farmers behavioral intention to adopt digital platforms for sustainable and successful agricultural ecosystems. *Technological Forecasting and Social Change*, *204*, p.123436. https://doi.org/10.1016/j.techfore.2024.123436