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Review Article

A Review of Agent Based Interoperability Frameworks and Interoperability Assessment Models

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Abstract: In a heterogeneous world, concurrent distributed development has led to many types of multi-agent systems that offer diverse functionality in agents as different types of platforms are not in a position to interoperate. Agents from different platforms are likely to use different types of messages or message formats and the interpretation is likely to differ. The main driver for interoperability is partly the customer who strives for universality when accessing multiple services, and partly producers who often need to act in fast to obtain a sustainable customer base. Implementations of agent systems differ greatly in architecture thereby negatively affecting interoperability, system diversity, rapid proliferation of agent technology, and advancement of the industry. In order to standardize some aspects of agent technology, considerable research has been conducted in the area of interoperability of agent technologies. Hence, it would be interesting to find out what agent systems interoperability frameworks have been proposed in the last few years. It would also be interesting to find out what interoperability assessment models exist. To address these issues, this paper presents the findings of a comprehensive literature review conducted with the aim of establishing existing agent based interoperability frameworks and interoperability assessment models.
Keywords: Interoperability, interoperability frameworks, maturity models, assessment models, agent systems, interoperability levels.

INTRODUCTION

Interoperability is considered a critical success factor to forge ahead in the online provision of services. There is wide agreement in administrative practice and research that the use of ICT will only lead to savings and improvements if business processes are reorganized in order to allow for a seamless exchange of data between all agencies involved [1]. Developing interoperability implies establishing measures of merit to evaluate the degree of interoperability. Maturity is one of the possible measures, describing the stages through which systems can evolve to reach higher degree of interoperability. The interoperability maturity assessment allows companies knowing their strengths and weaknesses in terms of ability to interoperate with others, and defining priorities to improve interoperability. Interoperability according to available literature can deepen technology adoption and improve on growth scale implementation and therefore further leading to saving of the associated operational costs, while at the same time benefiting the consumers. Interoperability has been known to force the telecoms companies to compete better on services, cost and convenience and give consumer better choices [2]. To ease large-scale realization of agent applications there is a need for frameworks, methodologies and toolkits that support the effective development of agent systems. Moreover, since one of the main tasks for which agent systems were invented is the integration between heterogeneous software, independently developed agents should be able to interact successfully [3]. This paper sets out to explore the literature surrounding agent based interoperability frameworks and interoperability assessment models.

The rest of this paper is structured as follows: Section 2 presents the background information, section 3 presents existing interoperability frameworks, section 4 presents interoperability assessment models, section 5 presents a discussion, and section 6 presents the conclusions.

BACKGROUND

Agents

An agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives [4-5]. An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators [6]. According to [7] an agent is something that acts in an environment, interact with the environment with a body, receive information through their sensors, and act in the world through their actuators, also called effectors. Another definition is that an agent is a special software component that has autonomy that provides an interoperable interface to an arbitrary system and/or behaves like a human agent, working for some clients in pursuit of its own agenda [8]. Agent based system in this paper refers to systems that use agents (special software components) to provide interoperable environment. The next section gives a brief description of the following types of agents: Intelligent agents, Software agents and Mobile agents.

Intelligent Agent is one that is capable of flexible autonomous action in order to meet its design objectives [4]. *Software Agent* is loosely defined as a program that can exercise an individual's or organization's authority, work autonomously toward a goal, and meet and interact with other agents and its environment [9]. *Mobile Agent* has the same features and characteristics as software agent with an added capability that is mobility. A mobile agent is software, together with data, which can be executed in a certain host to do a task and then move to another host to continue its execution [10]

Interoperability

Definitions.

A number of reports and technical papers have defined interoperability in a number ways focusing on different components of interoperability such as operational components and technical components. In [11-13] interoperability is defined as the ability of two or more systems or components to exchange information and to use the information exchanged. In [14], interoperability is defined as an on-going process of ensuring that systems, procedures and cultures of an organization are managed in such a way as to maximize opportunities for exchange and reuse of information. Interoperability has also been defined as the ability of ICT systems and the business processes they support to exchange data and share information and knowledge and as the ability to transfer and use information in a uniform and efficient manner across multiple organizations and information technology systems [15-16]. Interoperability has also been defined as the ability of Government organizations to share and integrate information and business by using common standards [17].

Interoperability is the ability of a system or a product to work with other systems or products without special effort on the part of the customer, and this is made possible by the implementation of standards [18]. Interoperability is the ability of two or more systems or applications to exchange information and to mutually use the information that has been exchanged [19]. Interoperability is the ability of independent systems to exchange meaningful information and initiate actions from each other, in order to operate together to mutual benefit. In particular, it envisages the ability for loosely-coupled independent systems to be able to collaborate and communicate [20]. Interoperability has also been defined as being able to accomplish end-user applications using different types of computer systems, operating systems and application software, interconnected by different types of local and wide area networks [21]. Other definitions of interoperability include a solution that enables two or more software applications to exchange data and achieve a common objective, even if the two applications were not originally intended to cooperate. However, interoperability can take place at different governance levels; i.e. from the exchange of simple data items, to structured documents (e.g., a purchase order), to business process cooperation where different organizations are enabled by interoperable software applications to achieve a common objective [22].

From these definitions of interoperability, one main common thread found among them all is the ability to exchange data and information among multiple organizations. Thus, the working definition for this paper is the ability of two or more systems or their components to exchange meaningful information electronically, securely, accurately and verifiably, when and where needed; and initiate actions from each other, in order to operate together to mutual benefit. This definition conforms to [20]. Technology policy experts acknowledge that complex technical problems remain to be solved, but ultimately the successful interoperability will depend more on the consensus and cooperation of people than of machines [23].

Types of interoperability.

Interoperability is a function of operational concepts and scenarios, policies, processes, and procedures [24] in heterogeneous domains. Organizational entities that manage data are autonomous in adopting the architecture, design and communication technology. Architecture and design autonomy give them leverage to adopt any architecture/design suitable for holding the data across the organization. Communication autonomy comes into existence when organization is willing to share data with different architectures, vendors or solutions. In interoperability, element of associative autonomy [25] has to be there to control autonomy at different level of data sharing across the organization for inter/intra communication and exchange of information. Interoperability is categorized into many different types

[26-28]. The following section discusses various types of interoperability.

Technical Interoperability denotes the interoperability of infrastructure and software. Infrastructure interoperability is the ability of hardware acquired by different organizations to work in a connected way. It makes heterogeneous systems of systems a reality [10]. Technical interoperability is associated with the hardware and software components, networks and equipment that enable machine-to-machine communication to take place. This includes aspects such as open interfaces, connectivity, data integration, middleware, data presentation, data exchange, accessibility and security issues [29-30].

Syntactic Interoperability deals with the data representation in machine readable form and usually associated with data formats [30]. Intent is to identify elements, rules for structuring the elements, mapping, bridging, and crosswalks between equivalent elements [31]. Syntactic interoperability helps in making two or more systems capable of communicating and exchanging data.

Semantic Interoperability is concerned with ensuring that the precise meaning of exchanged information is understandable by any other application that was not initially developed for this purpose [32]. Semantic interoperability is a must to ensure only relevant information can be exchanged or shared. It will support high level, context sensitive information request over heterogeneous information resources, hiding system, syntax and structural heterogeneity [33]. To achieve semantic interoperability, both sides must refer to a common information exchange reference model [32], [34].

Data Interoperability means single data definition for all systems. Interoperability at the data level requires involvement in the development of standards for data descriptions (catalogues and reference data), data access (database interfaces), and data transport (representation and protocols) [35]. The basic idea is that shared data is stored only once and maintained by the producer. In this way, data in use should be up to date and no redundant versions need to be stored [36].

Organizational Interoperability is concerned with the ability of two or more units to provide services to and accept services from other units, and to use the services so exchanged to enable them to operate effectively together [37]. Each organization brings its own unique culture, capabilities and operating procedures to the table [38]. Organizational Interoperability heavily depends on successful implementation of technical, syntactical and semantic interoperability [39].

Levels of interoperability.

Interoperability taxonomy is extensive in the context of mobile money. The CGAP has proposed a framework that distinguishes between several different levels of interoperability [40]. The three main levels of interoperability are: Platform-level interoperability, Agent-level interoperability and Customer-level interoperability.

Platform-level interoperability is where mobile money platforms are interconnected. A customer with an account with one service provider can send or receive money to or from the account of a customer with a different service provider and be able transact business with it, without going through agents. [41-43]. At the moment, no single market has interconnected mobile money platforms.

Agent-level interoperability revolves around the ability of a customer of one provider to use the agent of another provider for cash-in/cash-out services related to that customer's account. Agent interoperability is possible even when there is agent exclusivity (i.e. giving an agent the opportunity to consider your work exclusively and agreeing that you will not submit it to any other agent), as long as platforms are interconnected (such as with interoperable ATM networks) [41, 44].

Customer-level interoperability describes two interoperability scenarios related to the mobile handset: a customer's ability to access their account using any phone connected to the same network; or to access multiple accounts using the same phone [41, 45].

In the context of mobile money, [43] have proposed a framework that distinguishes between several different types of interoperability. In addition to the Platform-level, Agent-level and Customer-level interoperability discussed above, the framework proposed two more types as follows: Interconnection with financial institutions: one mobile operator, in one country, operating its own commercially and technically independent mobile money service, interconnecting its technical platform with the technical platform of a traditional financial services provider to enable interaction between the two platforms (i.e. the ability for a customer to send money from a mobile money account to a bank account, etc.) and Interconnection with other payment networks: one mobile operator, in one country, operating its own commercially and technically independent mobile money service, interconnecting with a separate payment system (i.e. connecting with the Visa or MasterCard payment networks) [43].

INTEROPERABILITY FRAMEWORKS

An interoperability framework is defined as a set of standards and guidelines that describes the way in which organizations have agreed, or should agree, to interact with each other [46]. An interoperability framework is, therefore, not a static document and may have to be adapted over time as technologies, standards and administrative requirements change [46]. In [47] Interoperability framework is an architecture where a composite of processes is implemented as an interconnected queue of smaller, less complicated tasks.

The sections that follow give an analysis of interoperability frameworks, citing their limitations. The frameworks discussed include: Mobile Agent System Interoperability Facility (MASIF), Foundation of Intelligent Physical Agents (FIPA), FIPA & MASIF Framework and Grid Mobile Agent System (GMAS) Framework.

Mobile Agents System Interoperability Facilities (MASIF)

The MASIF framework is a standard for mobile agent systems which has been adopted as an Object Management Group (OMG) technology [48]. Its' main goal is to promote a higher level of interoperability between different agent platforms or systems. It offers a collection of definitions and interfaces that provides an interoperable framework for mobile agent systems. The MASIF framework for mobile agent systems is based on the famous Common Object Request Broker Architecture (CORBA) [49-51]. The framework focuses on interoperability between agent systems written in the same language expected to go through version updates. It has achieved standardization of Agent management (i.e. managing agent systems of different types via standard operations in a standard way e.g. creation, suspension, resuming, and termination of an agent), Agent transfer (i.e. free movement among agent systems of different types), Agent and agent system names (i.e. standardized syntax and semantics of agent and agent system names that allow agent systems and agents to identify each other, as well as clients to identify them), and d) Agent system type and location syntax (i.e. the location syntax is standardized so that the agent systems can locate each other). MASIF addresses security in mobile agents, i.e. when agents are transferred or created from remote clients, the clients and the involved agent systems are mutually authenticated automatically [52].

MASIF suffers from many limitations such as: How can regions be interconnected? How can an agent system receive an incoming agent of a different agent system type? How may heterogeneous agents communicate? Moreover, it appears that mobility makes the reuse of today's CORBA services neither simple (e.g. naming), nor sufficient (e.g. security) [53]. The MASIF framework, in its current form provides features required for the first level of interoperability which is the transport of agent information where the information format is standardized. Once the information is transferred from one agent system to another, how the agent system deals with the parameters is an implementation matter and not addressed by the MASIF standard. In order to address interoperability concerns, the interfaces have been defined at the agent system rather than at the agent level. MASIF does not address Language interoperability for active objects neither does it standardize local agent operations such as agent interpretation, serialization or de-serialization, and execution.

Foundations of Intelligent Physical Agents (FIPA)

The FIPA framework was established in 1996 as an international non-profit association of companies that agreed to share efforts to produce standard specifications of generic agent technologies that were: produced in a timely fashion, internationally agreed and usable across a large number of applications so that a high level of interoperability across applications is achieved [54-56]. Therefore, FIPA framework's main goal is to advance the development of specifications of generic agent technologies that maximize interoperability within and across agent based applications [3]. The framework provides specifications on a wide variety of topics and issues; firstly, it defines a set of key components for developing agent systems. Secondly, it puts in place a number of parameters that take care of interoperability in areas like: standard interactions, protocols for complex message interaction, agent communication language syntax, content language syntax, etc. Lastly, it supports flexibility in the agent interaction requirements and provides general reference models. FIPA mostly focuses on specifying external communication between agents rather than the (internal) processing of the communication at the receiver. To achieve flexibility in a basic FIPA specification, an agent is not compelled to answer to a message which creates the problem of how to establish the termination of an interaction [57].

Despite FIPAs' role in advancing interoperability, it does not define patterns of composition which would support agent development for interoperability. Moreover, semantics are based on mental agency, hence do limit interoperability. The framework does not provide any specifications for useful tools like debuggers or message tracers and support of such tools has been left to the specific agent platform employed [57].

Grid Mobile Agent System (GMAS) Framework

Another interesting interoperability structure is the Grid Mobile Agent System (GMAS) [58]. It allows foreign agents to execute in a non - native mobile agents system by translating the foreign agent's Application Programmer Interface (API) into the local platform's API and provides methods to create an agent either by launching a new agent or by cloning the current agent to a remote host. GMAS precisely addresses the issues of parking or unpacking and transferring of an agent in a platform independent manner and subsequent APIs of different mobile agent systems. Moreover, GMAS is scalable in the number of mobile-agent systems, since only two adaptors are required per agent platform, rather than one adaptor per each different pair of platforms. However, the current GMAS implementation does not address any security issues; secure communication and secure agent transmission is provided by the communication transport layer.

Enterprise Interoperability Framework (EIF)

The Enterprise interoperability framework can be used to structure interoperability knowledge. This framework shows the conceptual interoperability barriers. It also shows the use of the framework to identify and categorize the knowledge that remove both syntactic and semantic barriers but is limited to process level and few common attributes were not considered such as negotiation, agreement, learning and performance. Thus, EIF is poor in addressing aspects related to the learning ability of a system and its member organizations and also does not address security aspects of e-communication e.g., confidentiality, authentication, nonrepudiation [59].

INTEROPERABILITY ASSESSMENT MODELS

Achieving interoperability requires a coordinated process among all the stakeholders. Advancing interoperability requires an improvement process [60]. The fact that interoperability is a process and not a single event that can be forced in companies, attract the relevance of Maturity models which describe the stages through which systems, processes or organizations progress or evolve as they are defined, implemented and improved. Maturity assessment allows companies to know their interoperability strengths and weaknesses and define priorities to improve interoperability [61], [62]. A variety of interoperability maturity models have been developed, each adopting a unique vocabulary to express their characterization of interoperability capability maturity. These maturity models address certain specific problem domains.

LISI Reference Model

In 2003 the Levels of Information Systems Interoperability (LISI) project was initiated by the C4ISR Integration Task Force to address the specific requirements of C4I (Command, Control, Computer, Communication and Intelligence) domain. The outcome of the LISI project was a LISI reference model and process for defining, assessing and certifying the degree of interoperability required or achieved between organizations or systems. There are several key concepts in this reference model. The first is providing an interoperability maturity model to describe levels of sophistication regarding information exchanges. Next, LISI provides requirement organizations the ability to identify operational and system requirements in terms of interoperability. Third, the LISI construct has a suite of capabilities associated with the procedures, applications, infrastructure, and data domains in order to obtain the desired level of capability. Finally, LISI provides a practical assessment process for determining the interoperability of a given system or across a system pair. This process uncovers capabilities that may be lacking in the systems, areas not compatible and options for resolving the deficiencies so the systems can move to a higher level of interoperability [63-64].

However, LISI has a number of limitations. The first complaint is that the LISI construct is centered strongly on technology, and more specifically, as its name suggests on information exchanges [65]. The model does not address the organizational issues that contribute to the development and maintenance of interoperable systems [66]. Another limitation of the LISI construct is in its difficulty and complexity in implementation. "At its core, LISI, is based around classifying levels of interoperability by the 'richness' of communication that a particular system or group of systems allow. The model has been criticized for being too complicated for use when aggregating the status of a system at the simple level [67].

Organizational Interoperability Maturity Model (OIMM)

The organizational interoperability maturity model was proposed by Clark and Jones [65]. It serves to compliments the LISI model (which was rather more of technical interoperability) by including the organizational interoperability perspective. Interoperability models reviewed so far define interoperability maturity levels with the main differences between the models being their focus and the manner in which they rate interoperability. The models reviewed are partial that deals with some aspects of the entire interoperability domain. Therefore interoperability maturity models covering all aspects of mobile phone interoperability are missing. OIMM selection of technology standards does not guarantee semantic or organizational interoperability. Even though there are languages for modeling information meaning and processes to support interoperation in these areas, the fundamental limitation is human agreement. Also there are risks in relying on standards to achieve technical interoperability.

Government Interoperability Model Matrix (GIMM)

The Government Interoperability Model Matrix (GIMM) is another model that can be used by organizations to assess their current e-Government Interoperability status in respect to interoperability readiness and performance. The GIMM model was proposed by [68-69]. The GIMM defines five different sets of organizational interoperability maturity levels, where each level corresponds to a different interoperability level for a set of Interoperability Attributes (IA). The organizational interoperability maturity levels defined in GIMM are closely aligned to the CMMI reference model and to LISI. The GIMM maturity levels are the following: (1) Independent, (2) Ad-hoc, (3) Collaborative, (4) Integrated and (5) Unified. Achieving Interoperability at Local Level in the GIMM model arguably involves a mix of policy, management, as well as technology dimensions. The same case can be made for Metadata in the IMM model and Legal, Environment, Security, and Trust in the EIMM model. As a result, one challenge government manager's face in applying these existing interoperability maturity models is recognizing that each of these capability dimensions requires a mix of diverse yet interdependent and interacting capabilities to improve interoperability [70].

Enterprise Interoperability Maturity Model (EIMM)

The EIMM defined as a set of Areas of Concern and a set of maturity levels provides the means to determine the current ability of an enterprise to collaborate with external entities and to specify the path to improve this ability. It provides an organizational context for more specific and technical improvements. As a third dimension, the EIMM takes into account the targeted organizational units for which a maturity level needs to be assessed, or which need to be improved, in order to achieve a certain maturity level [71]. EIMM deals specifically with enterprise modeling assessment, which mainly concerns conceptual barriers of interoperability. It focuses on the use of enterprise models and the maturity of their usage, which requires a correct syntactic and semantic representation [72] EIMM aims at measuring enterprise model maturity and covers main enterprise model views such as function, service, process, data, information, organization as well as other aspects such as business strategy, legal environment, security and trust. EIMM has limitation in that deficits and gaps during operation leads to a serious risk related to the current business.

Information Systems Interoperability Maturity Model (ISIMM)

To assess the degree of interoperability between Information Systems, a more practical Information Systems' Interoperability Maturity Model (ISIMM) was developed to meet the objectives stated previously. The ISIMM was derived from the theories of LISI and GIMM and specifically focuses in more detailed on the technical aspects of interoperability that would allow data to be shared and exchanged within an information systems environment. Specially, ISIMM defines five levels and degree of interoperability sophistication that an organization's Information Systems will progress through and follows: (1) Manual (2) Ad-hoc (3) Collaborative (4) Integrated and (5) Unified. The levels of ISIMM provide a structured and systematic approach for assessing and measuring Information Systems' interoperability maturity. In addition to exploring the complexities of interoperability, ISIMM provides the means to attain a deeper understanding of Information Systems' interoperability that will help to promote and establish an interoperable systems environment within government. The current ISIMM model and its assessment framework could be made more inclusive by including aspects of organizational interoperability in particular business process interoperability that would allow end-to-end e-Government services [73].

Capability Maturity Model for Software (CMM)

The Capability Maturity Model for Software (CMM) [68] developed by the Software Engineering Institute (SEI) is the most popular process improvement approach that provides organizations with the essential elements of effective processes. The CMM describes the principles and practices underlying software process maturity and is intended to help software development firms improve the maturity of their software processes in terms of an evolutionary path from ad hoc, chaotic processes to mature, disciplined software processes. The CMM is organized into five maturity levels: a) Initial b) Repeatable c) Defined d) Managed and, e) Optimized. With CMM the evaluation of the maturity level of an organization is based on the evaluation of the capability levels of single processes.

Some limitations of the CMM include: When organizations use CMM, they look at each level as a target which is dangerous because if you become fixated on reaching the next level, you begin to lose perspective and forget that the real goal is to actually improve the processes [74]. Again, the CMM does not specify a particular way of achieving goals. In order to achieve them one needs to think in a flexible way. The goals are only achieved if the firms' processes are taken into account, as each firm is different so the steps needed for process improvement are different. Just because one organization follows the rules set by the CMM does not guarantee that it will be successful as there are other factors involved. Another drawback is that CMM only helps if it is put into place early in the software development process. It can't be used as an emergency method of recovering from a difficult situation. Finally, CMM concentrates more with the improvement of management related activities but improved quality of code may be a vital issue in the context of software.

DISCUSSION

The interoperability frameworks reviewed in this paper were found to contain a number of limitations. Some of the issues not addressed by either of the interoperability frameworks i.e. MASIF, FIPA, EIF or GMAS include security issues, agent mobility and agent communication/language. For example, MASIF handles security issues quite well, whereas, the current GMAS and EIF implementation does not address any security issues. FIFA specifications address agent communication, whereas MASIF specification does not address agent communication. FIPA specification does not address agent mobility, whereas MASIF specification addresses agent mobility quite well. Interoperability regarding security issues is not solved with the integrated platform of FIPA and MASIF. Therefore, there is need to integrate these standards to come up with an interoperability framework that addresses most aspects of any system.

The maturity models reviewed mainly focus on one single facet of interoperability (data or technology or conceptual etc.) and do not have a general view of the enterprise interoperability domain. So, when an enterprise needs to assess its whole interoperability, it has to use one maturity model for each interoperability field or concern (i.e. business interoperability, conceptual interoperability, technical interoperability, data interoperability, etc.). The use of more than one model to assess enterprise interoperability creates redundancies and incompatibilities and makes the aggregation process more difficult. Interoperability aspects are not covered by a single maturity model. Instead, each of the studied models covers mainly one aspect of interoperability and consequently deals with one interoperability barrier [71].

The LISI, OIMM, EIMM, ISIMM and CMM models are partial models, meaning that, they only deal with some interoperability dimensions and leave out others. It is necessary to structure them into a single complete interoperability maturity model to avoid redundancy and ensure consistency [75]. An interoperability maturity model covering all main areas of concerns and aspects of the interoperability still does not exist. There is also a need to identify properties and metrics to allow better characterizing and measuring interoperability potential. Existing interoperability maturity models were not developed to a satisfactory level to measure explicitly potentiality. Although the LISI model proposes potential measurements of interoperability, it is still specific to information systems and misses other aspects involved in an enterprise interoperability context. Based on this analysis, the reviewed maturity models are complementary. A further analysis of these models is needed with the aim of finding out, which ones are the most relevant to mobile money interoperability and then extending them as appropriate.

CONCLUSIONS

In this paper, we discussed various agent based interoperability frameworks and interoperability assessment models, with an intention of citing what they can do and their limitations. While this paper does not offer a conclusive answer to the question of how to design a wholistic interoperability framework, it does bring out limitations of the already existing frameworks, thus giving insights for improving interoperability frameworks. The paper has also shown clearly, that interoperability is not a characteristic of a single system but rather a characteristic of the relationship between two or more systems in a particular context. The context in which systems have to interoperate shapes the requirements that each individual system has to satisfy in order for it to interoperate with other systems. Thus, developers need to plan system components around both technical and nontechnical aspects of interoperability. Since, interoperability is a condition of success for process deployment in companies; it should be assessed along deployment stages. Models further helps organizations to take a functional view of their interoperability both at organizational and at an information system level. Interoperability assessment models reviewed so far define interoperability maturity levels with the main differences between the models being their focus and the manner in which they rate interoperability. The models reviewed are partial, meaning that they lack certain aspects of interoperability. Therefore, interoperability maturity models covering all aspects of enterprise interoperability is missing.

Future work includes developing a platform-level interoperability framework for mobile money payment services. Another future work is to develop an interoperability assessment model that can be used together with the interoperability framework. Such a model can be used to measure the extent of maturity of interoperability between the various mobile services provider platforms.

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