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Cellular Network Service Dependency Modeling for Network Faults Prediction

Okuthe P. Kogeda

***Abstract* - Cellular network service providers are investing heavily in Long Term Evolution (LTE) with the objective of providing innovative services and superior user experience to customers. The objective can only be attained with a network that operates to its full potential with no or minimal network faults occurrences. Cellular network services depend on certain network elements and even some network services to operate fully. Network services are dependent on network elements that support disparate objects within the network environment. These network elements must be fully operational to support network service consumption. Network faults can however affect the network elements and hinder them from supporting network services. In this paper, we present a self-healing capability of the cellular networks that supports network faults to be detected, predicted and their effects masked to customers proactively while repairs are done on the cellular network elements that support the network services. This is presented in the form of cellular network service dependency models that provide proactive re-organization of network elements depending on their availability, which is determined by network faults. The basics, types, benefits, and life cycle of cellular network service dependency are also provided. The simulation results showing 99.95% dependency are provided in this paper.**

***Index Terms* — LTE, Self-healing network, Network services, Network service dependency, Network faults.**

I. INTRODUCTION

The current rollout of fourth generation (4G) networks popularly known as Long Term Evolution (LTE) is creating high expectation of customers. This is coupled with internet explosion, increasing number of subscribers and services on offer has put a lot of pressure on the cellular network service providers not only to provide new innovative services but also ensure superior user experience. The networks are loaded with different kinds of subscribers having different tastes and needs. This requires that the operation of the network be at its best all the times not only to keep the subscribers happy but also to retain them and attract new ones. This requires maintenance of the network itself and one that can proactively re-organize elements and be able to perform self-healing. A self-healing network is one that can fix its own broken communication links [1].

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Cellular network service is a crucial and very important resource that any cellular network service provider desiring to retain and acquire new subscribers, must ensure it is general, cost effective, fair robust, reliable and have high performance connectivity among a large number of communication devices (i.e., computers, wireless terminals, etc.), for the highest customer satisfaction.

The ITU-T defines telecommunication services as [2]: A *service* represents telecommunication capabilities that the customer buys or leases from a service provider. Service is an abstraction of the network-element-oriented or equipment-oriented view. Identical services can be provided by different network elements, and different services can be provided by the same network element. An application on the other hand is a generic term that represents a set of features, combining communication and document processing, on which end users may perform operations. An *application* is a program that a user directly interacts with. An application utilizes services and might incorporate modules to fulfill its tasks.

The common characteristics of cellular network services include: services can use one or more media of transmission; most services being offered by cellular service providers are easily programmable and flexible to the needs of customers; most services are easily accessible with cost and legal permission to use them; cellular network services are randomly initiated and executed.

A set of applications with similar or common set of characteristics can be classified as a service. Generally cellular network services can be classified into data, voice and multimedia according to ITU-T I.211 [2]. Network services in digital form are called data. Network services in 'vocal chord' form are called voice and are regarded as the oldest cluster of network services. Network services, which are normally composed of pictures, videos, text and/or sound, are called multimedia. Multimedia services consume a lot of bandwidth and require powerful devices to be able to receive and send them.

This paper is organised as follows: In Section II, we give a brief overview of Cellular network service dependency, types of network service dependencies and benefits of network service dependency modelling. Dynamics and network dependency life-cycle are presented in Section III. In Section IV, cellular network service dependency models are presented. In Section V, simulation results are provided and then we draw conclusion in the subsequent section.

II. CELLULAR NETWORK SERVICE DEPENDENCY

The consumer/provider relationship between different entities in a cellular network system is called dependency. When one component requires a service performed by another component in order for it to execute its functions, this relationship between the two components is called a dependency. For example, a voice service depends on a cell where it is located for network signal and the database for billing purposes before a call is initiated. In turn these services depend on availability of power supply. In this case a voice service is the *dependent* and cell and database are the *antecedent*. Consequently, cell and database are the *dependents* and power is the *antecedent*. This relationship is shown in Figure 1. Services cannot be considered isolated tasks. Services very much depend on other services or sub-services, lower level network elements, operating systems, physical components and communication infrastructure to be able to function.

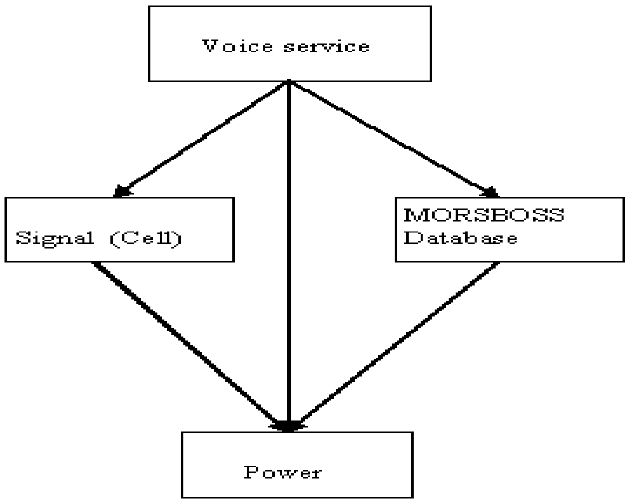

Figure 1: Example of Service (voice) Dependency

Network service dependency has attracted several researchers with different viewpoints. Ensel [3] presents a scalable service dependency. The author used neural networks for dependency detection modeling. Cervantes et al [4] present a mechanism to automate service dependency management in a service-oriented component model. They used a mechanism that eliminates complex and error-prone code from component-based applications dynamically. Gruschke [5] proposed dependency graph for event correlation where dependency was described as a relationship between different entities. A generic approach proposed here could be used for different abstraction levels (i.e., system level, network level, service level). Caswell et al [6] describe dependencies for services with specific reference to Internet Service Providers. They went further by defining five types of dependencies. Gupta et al [7] present analysis of temporal relationships of interactions to derive dependencies. The approaches presented above fail to identify, detect and predict which network service would be affected by a network fault. In this work, an approach of dynamic dependency with a view of self-healing network is used to pre-empt the likely services that a likely network fault would affect. While some of the approaches above cannot be implemented, the approach adopted in this work can be implemented backed with mathematical support.

A. Types of Network Service Dependency

The main types of service dependency include [3][8][9]:

Execution dependency – This dependency relates directly to an application server process being executed on a host machine. The performance of an application server process depends on the status of the host machine. The types of application servers that are executed on host machines include web, email, news, DNS, and NFS.

Link dependency – performance of a service depends on the link status, i.e., the communication between two nodes, *A* and *B*, may solely depend on the link between them *AB*.

Component dependency – in case of a web service that is provided on different front-end servers, which are selected by a round-robin DNS scheduling the performance, depends on the currently selected server. A component dependency occurs in order to ensure scalability and redundancy of a service. ISPs often replicate web, email, and News content across a number of servers. The round robin scheduling balances the load among the servers.

Inter-service dependency – It occurs when one service accesses another service for its proper operation. This occurs between services, i.e., e-mail service depends on an authentication service and on an NFS service.

Organizational dependency – It occurs when there are different ISP operations personnel (e.g., experts) who are responsible for different services and service components, i.e., an ISP may have a first supervisor managing the web service, a second supervisor managing DNS, and a third supervisor managing NFS. Operational responsibilities may also be delegated based upon the geographical location of the service components.

The first three dependencies are grouped and referred to as *resource dependency*. In this case the service being offered depends on the resources (i.e., execution, link, component, and/or another service) available at the time. These resources in turn are affected by the cellular network faults, i.e., faults may degrade, reduce or totally take away the resources available to a service.

B. Benefits of Network Service Dependency

The main benefits of dependency modeling include [3]:

1. *Root cause analysis* – it helps to find a common (root) cause of faults detected at different places within the cellular network environment. This can be used on network components reporting error conditions as well as to services, where end users detect problems. The faults that are normally reported to the management systems are descriptions of the symptoms. Therefore further knowledge about dependencies among the faults is necessary to derive their root cause.

2. *Determination of availability requirements on services*- this would help to minimize the time for resolving network fault.

3. *Prediction of the impacts on other services due to management operations* - this is of particular interest when a resource goes down (for repairs) then it can be determined in real-time which services and customers are affected. It can be the basis of scheduling tasks and transactions. The service dependency provides a detailed task structures,

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which enables coordination of services better. It can be used to recognize service misuse and intrusion detection.

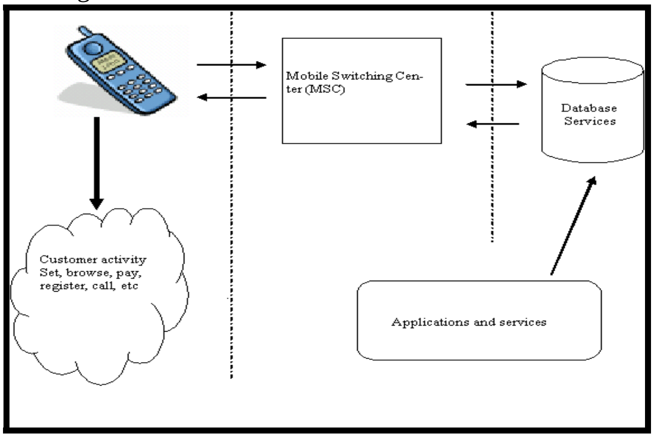

Figure 2: Model of Network Environment Showing Dependency

In order to derive the problem solving process that is cellular network faults prediction, a model of cellular network faults, or a concept of services and dependencies between them is required. A cellular network service can be defined as a set of functionalities, which are offered by a cellular network service provider to a customer at a customer provider interface (i.e., mobile handset) with an agreed quality of service (QoS). A service can depend on one or more resources and a resource can be used by one or more services. To ensure high quality of services is provided, it is necessary to react accurately to faults occurring in one or more components that provide such resources. This can be achieved by determining the dependencies between different services, dependencies between services and resources and dependencies on the resource level. It will be better also to bring to clarity what an interface and a component stand for. *A component* is a non-trivial, nearly independent, and replaceable part of a cellular network system that fulfills a clear function in the context of a well-defined architecture. A component conforms to and provides the physical realization of a set of interfaces. An *interface* is a collection of operations that are used to specify a service of a component. It focuses upon the behavior, not the structure of a given service. Figure 2 shows a model of cellular network environment showing dependency.

III. DYNAMICS AND DEPENDENCY LIFE CYCLE

A. *Cellular Network Service Dependency Dynamics*

Cellular network service dependency changes as variables within the cellular network setup changes. The changes are normally caused by resources (network components, services, power, etc.) becoming unavailable due to network faults, resources may migrate, or may be upgraded. In a cellular network, the components and/or managed objects that represent the resources may be many. The change of dependency that may occur as a result of fault in a cellular network is termed as *cellular network dependency dynamics*.

Cellular network services can be modeled as node, communication and precedence constraints between services as directed edge and the model can be expressed as a Directed Acyclic Graph (DAG). Let the service be *S*, $S=\{s_1, s_2, s_3, ..., s_N\}$. A complex cellular network system may offer *N* number of services. A service depends on resource(s) *R*, where $R=\{r_1, r_2, r_3, ..., r_j\}$. A resource can be network link, component, or other services. An edge between two services, S_a and S_b is given by S_{ab}, which expresses the dependent relation between S_a and S_b. Given service S_N the set of parent services is denoted as $pred(S_N)$, and the set of children services is denoted as $succ(S_N)$. A service S_N is called entry service if $|pred(S_N)|=0$ and an exit service if $|succ(S_N)|=0$. Therefore *N* services depend on *R* heterogeneous resources. It is essential to map the set of *N* services in the DAG into *R* heterogeneous available resources in order to avoid the faulty components supporting the resources required by the services.

The dependency relation between S_a and S_b may change, i.e., if S_b malfunctions then S_a (will also fail in normal circumstances) but in this case S_a may use another service say S_k, which offers the same resources for its operation. Also if S_a depends on a particular route (link) R_l then with the failure of R_l, S_a is also expected to fail. But this may not be the case because S_a may use another route to complete the execution. The network organizes itself and performs the self-healing in the face of network faults.

The system implementation takes into consideration this dependency dynamics with the cellular network system. Therefore, for a system to fail, it means all the alternative dependencies are exhausted. The main causes of dependency dynamics include: cellular network faults, which may cause the cellular network resources to appear and disappear during the system lifetime; deployment of new sub-systems; change of resource availability; re-negotiation of new service level agreements, etc. However, it is worth noting that most of the dependencies are fairly permanent and only change when there is deemed fault with one of the main antecedent. This is the main interest in studying how cellular network faults may change the dependency and its subsequent effects on the reliability of the network services.

B. *Cellular Network Dependency Binding*

The three main variables, faults, *F* where $F \rightarrow \{f_1, f_2, f_3, ..., f_i\}$, resources, *R*, where $R \rightarrow \{r_1, r_2, r_3, ..., r_j\}$, and services, *S*, where $S \rightarrow \{s_1, s_2, s_3, ..., s_N\}$ depicting the relationship between them, which can be one-to-one, one-to-many and many-to-many. The dependency only exists when cardinality between dependent and antecedent is exactly one. The maximum cardinality between the objects is infinity. The relationship between the variables can take either of the two sets below:

(a) The network faults relates to resources directly as follows:

(i) A set of faults can affect a set of resources in the network, $F \rightarrow R$

(ii) A set of faults can affect one or a particular resource in the network, $F \rightarrow r_j$

(iii) One or a particular fault can affect a set of resources in the network, $f_i \rightarrow R$

(iv) One or a particular fault can affect one or a particular resource in the network, $f_i \rightarrow r_j$

(b) The network services depend on network resources directly as follows:

(i) A set of services depend on a set of resources in the network, $R \leftarrow S$

(ii) A set of services depend on one or a particular resource in the network, $r_j \leftarrow S$

(iii) One or a particular service depends on a set of resources in the network, $R \leftarrow s_N$

(iv) One or a particular service depends on one or a particular resource in the network, $r_j \leftarrow s_N$

A binding which can be static or dynamic would occur with the knowledge of cardinality. A *static binding* is where the dependency bindings cannot change at run time and the dependent service is guaranteed to be present the entire time the resource is available, whereas *dynamic binding* is where the dependency bindings can change at run time and service availability cannot be guaranteed. Network services would be affected differently by different types of bindings as summarized in Table I:

TABLE I: DIFFERENT TYPES OF DEPENDENCY BINDING

Binding Type	**Semantics of the dependency type**
One-to-One, static	A service is bound to one resource, any change invalidates the service.
One-to-One, dynamic	A service is bound to one resource; changes do not invalidate the service as long as it can be bound to another resource.
One-to-Many, static	A service is bound to at least one resource, any change invalidates the service.
One-to-Many, dynamic	A service is bound to at least one resource; changes do not invalidate the service as long as the binding count is not zero.
Many-to-Many, static	A set of services are bound to a set of available resources at the time of binding, changes invalidates the services.
Many-to-Many, dynamic	A set of services are bound to a set of all available resources at the time of binding, as resources become available/unavailable they are bound/unbound to/from the services, the services never becomes invalid.

C. *Cellular Network Service Dependency Life-Cycle*

Cellular network environment is very dynamic in nature and so the dependency evolving through FIVE phases, referred to as *dependency lifecycle*. The phases include:

1) Initiate: This is the initial phase where the dependency is initiated when service consumption is signaled. The initial parameter values are received at this stage. For example, when you initiate a call, first the signal is acquired to have connection to the MSC, and then database connection is initiated to establish whether you have enough units to continue with the service consumption.

2) Acquire: existing services, resources, and common (known) faults are acquired by the dependency for mapping purposes at this stage. New and old dependencies are ascertained mainly for consumption purposes, i.e., after service, S_a signaled service, S_k for dependency and received positive answer, then it acquires the resources in readiness for the dependency mapping to complete the service consumption through S_{ak}.

3) Start Map: This stage triggers the start of dependency mapping.

4) Map: new resources may be added to the dependency pool during this phase. Existing resources and dependency parameters may be removed or updated to ensure the dependency dynamics are maintained. Dependency mapping can be affected by these changes, and so must be resolved continuously for a robust cellular network system.

5) Stop: The dependency is terminated at this stage.

The dependency life cycle continues by initiating another dependency. The semantics of the dependency are implemented in the system, which correlates the network services to network faults. The service dependency life cycle is shown in Figure 3.

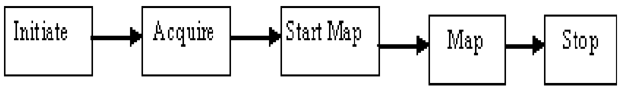

Figure 3: Dependency Lifecycle

IV. CELLULAR NETWORK DEPENDENCY MODELS

A cellular network environment can be logically modeled as layers of resources (i.e., services, applications and other software and hardware components) that cooperate to deliver an end-to-end service. Services or components in one layer depend on functions provided by components in a lower-supporting layer. Failures occurring in one layer affect the functioning of dependent components in another layer. The dynamics of service dependency are considered for cellular network faults prediction purposes, because significant changes in the overall system behavior are detected through emerging or disappearing dependencies. An understanding about network resources is important in service dependency modeling as explained in the following section.

A. *Network Resource*

"A network resource is any physical or virtual component of limited availability within a networked computer system. Every device connected to a computer system is a resource. Every internal system component is a resource. Virtual

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system resources include: files, network connections and memory areas" [10]. Network resources can also be referred to as various parts of the network (hardware and software) which support each other by combining or individually to provide specific functions within the network environment. Network service is created by these functions.

TABLE II: SUMMARY OF FAULTS, RESOURECES, AND SERVICES CORRESPONDINGLY

Faults	**Resources**	**Common Services**
Multiplexer	Link (lines), electrical power, Multiplexer adaptor, External Bus Interface (EBI) cable, conversion kit, port module, etc.	Voice, VoIP, Videoconferencing, etc.
Power	Generator, Electrical power sources, Electrical switches, transmission lines, etc.	SMS, MMS, Voice, VoIP, Email, etc. Virtually all services are affected.
Transmission	Link, cables, multiplexer, network name resolution, ISDN switches, ISDN lines, Gateways, etc.	Affect real-time services Affects services in a serial connection May delay services such as SMSs, etc.
Cell	Link, Electrical power, cables, multiplexer, etc.	VoIP, SMS, MMS, Email, Internet, Video conferencing, etc.
Time Out	Link, RAM, multiplexer, etc.	SMS, MMS, Email, VoIP, Video conferencing, etc.
Run Time Error	RAM, Link, Switches, etc.	VoIP, voice, Video conferencing, etc.
Out of Range	Signals, wireless access point, Internet, etc.	Voice, VoIP, email, SMS, MMS, etc.

Network resources are network elements that support services. A network resource can be basic or elementary. *A basic* network resource is the smallest element that supports a network service. It is scalar in nature and cannot be split further down. It supports the service with all its parts as a whole. A combination of two or more basic network resources to offer a function to a service is called *elementary* network resource. An elementary network resource cannot be used without any of the basic element parts. Table II above summarizes the list of faults, resources and services correspondingly.

Network elements (resources) support services through service access points (SAP) and port accesses. The services dependency is modeled keeping in mind the current changes happening to the network environment to proactively detect faults before they impact end users. Ontology is implemented in the system which facilitates the mapping of faults and services to list faults that are likely to cause network services failure.

B. Network Service Availability Models

One of the main aims of this work is to develop a reliable service based OSS where services would be available to users whenever they want to consume them. Availability of network services depends on availability of network resources to support them to carry out their functions. For example, an end-to-end service availability would depend on availability of service source, network link, and availability of the destination device. Network service availability is a combined availability of the network parts (elements) supporting the service(s). The combined availability is a product of the availability of all the network parts involved. This can be defined as:

$$SA = S(s) * N(s) * L(s) * Sw(s) * D(s) \qquad (1)$$

Where SA – Service Availability
$S(s)$ – Availability of service source
$N(s)$ – Availability of network
$L(s)$ – Availability of link
$Sw(s)$ – Availability of software
$D(s)$ – Availability of destination device

Equation (1) also means that the combined availability of the network is always lower than the availability of its individual components (resources). It is important to note that when network is available, the services being offered will also be available and vice-versa. Therefore, network availability directly impacts on service availability. Simply put,

$$NA = RA = SA \quad where \quad p(F) = 0 \qquad (2)$$

Where NA – Network Availability
RA – Resource availability
SA – Service availability
$p(F) = 0$ - is a probability of fault occurrence is 0 indicating fault-free network

The network availability at time, t for network service, s may be defined in terms of several parameters that includes network reliability $R(t,s)$, network maintainability $M(t)$ and fault effects $F(t)$ where,

$$NA(t,s) = R(t,s) + F(t,s) * M(t,s) \qquad (3)$$

Where $F(t,s) = 1 - R(t,s)$ (4)

However, the network reliability depends upon the reliability of many components that make up the network; i.e., network link, power, software, switches, and services. These set of components (resources) can be represented by $R \rightarrow (r_1, r_2, r_3, ..., r_j)$. Rewriting Equation (4) to know faults effects at time *t*, for service *s*, is

$$F(t,s) = 1 - (R(t,s))^j \qquad (5)$$

A given set of resources consisting of *R* members can be constructed with $R_\pi (\pi = 1,2,3,..., j)$ homogenous sub-populations.

$$\sum_{\pi=1}^{j} R_\pi = R \qquad (6)$$

A homogenous sub-population R_π is defined by the verifiable assumption that its members exhibit the same probabilistic decision behavior. However, these set of resources are affected by network faults. Network faults are errors that occur frequently within the network elements impairing their operations. Network faults may render the network elements unusable or partially working thereby

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diminishing partly or wholly the resources ability to carry out its functions depending on the faults impact.

A set of network faults $F \to (f_1, f_2, f_3, ..., f_i)$, can affect the network resources, R:

$$\alpha : F \to R \quad (7)$$

Where the domain α is the set *F*, the target of α is the set *R*

The range or image of α, written rng α, is

$$rng\alpha = \{r \in R \mid (f,r) \in \alpha \; for \quad some \quad f \in F\}$$
$$= \{r \in R \mid r = \alpha(f) \; for \quad some \quad f \in F\} \quad (8)$$

Therefore the function has its range of resources as the target of network faults given by $rng\alpha = R$; that is every $r \in R$ is of the form $r = \alpha(f)$ for some $r \in R$. Equivalently for any $r \in R$, the equation $r = \alpha(x)$ has a solution $x \in R$. The effects on network resources are transferred to network services with the function:

$$w : R \to S \quad (9)$$

The composition of α and w is the function

$$\alpha \circ w : F \to S \quad (10)$$

Equation (10) is defined by

$$(\alpha \circ w)(f) = \alpha(w(f)) \; for \quad all \quad f \in F \quad (11)$$

V. Simulation Results

In this Section, we use a case study of network voice service with a number of assumptions made during computation. Software availability was assumed to be 100%, other network faults were not considered except power fault, etc. Source availability, network availability, link availability, software availability, and destination device availability are 0.9958, 0.2343, 0.7737, 1.0, and 0.9958 respectively. We used Equation 1 to compute Service Availability (SA) and obtained 17.982%. Network availability (NA) was computed using Equation 3 and a value of 70.62% was obtained.

However, according to Equation (2), service availability is supposed to be equals to network availability. This is not the case here and it can be attributed to assumptions made, network fault's impact and other factors which are beyond the scope of this work.

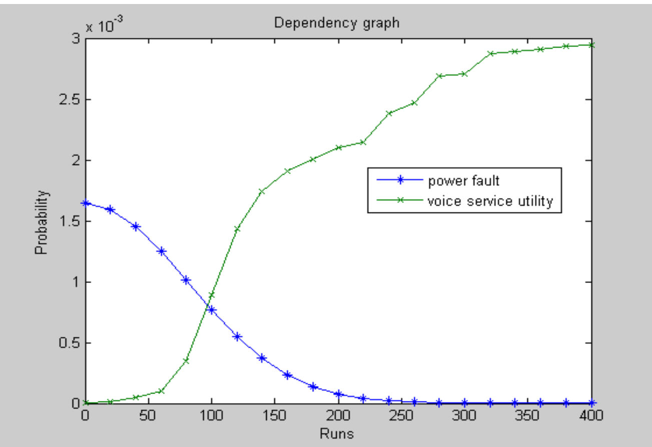

Figure 4: Network Service vs Network Faults Dependency

Network faults effects on network services at time *t* is given by Equation (5). The value of 99.95% shows that network faults directly affect network services. The margin of 0.05% can be attributed to noise. The utility of network service (in this case voice) improves with the reduction of network fault (in this case power) occurrence. Network faults occurrence and network service utility matched at the 100th iteration. This point is called acceptance point as shown in Figure 4

VI. Conclusion

The basics of network services delving on characteristics, classification and life cycle are provided in this paper. In our previous publication, we provided the classification and models of network faults prediction using Mobile Intelligent Agents (MIA), which are used to derive the dependency presented in the paper. The basics, types and benefits of network service dependency were presented. The dynamics and dependency life cycle were presented. Network service dependency models are presented with simulation results showing network services dependent on network faults. The results show 99.95% dependability of network services on network faults. The paper gave an insight on the relationship between network faults and network services that can help in network faults prediction and self-healing network [11].

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