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ATIS-0100037.2013(R2018)

Impact Weighted MTBF – A Metric for Assessing Reliability of Hierarchical Systems

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ATIS-0100037.2013(S2018), *Impact Weighted MTBF – A Metric for Assessing Reliability of Hierarchical Systems*

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Impact Weighted MTBF – A Metric for Assessing Reliability of Hierarchical Systems

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Abstract

The impact of failures in modern systems for voice and data transmission (e.g., IP routers or a Radio Network Controller) as well as mobility and wire-line communication networks with hierarchical design increases progressively with the hierarchical level. The Impact Weighted Mean Time Between Failure (IW-MTBF) – a combination of MTBF values for all hierarchical levels of a given network element or network segment weighted for each level by its respective impact on failures – is proposed as a method for evaluating overall reliability of the hierarchical system during the design phase.

Foreword

The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. As such, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Standard.

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Suggestions for improvement of this document are welcome. They should be sent to the Alliance for Telecommunications Industry Solutions, PRQC, 1200 G Street NW, Suite 500, Washington, DC 20005.

At the time of consensus on this document, PRQC, which was responsible for its development, had the following leadership:

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1 Scope & Purpose

Modern day Service Provider (SP) network architectures are continuously evolving to provide a growing and complex range of telecommunications services to their customers. From a reliability perspective, the evolving nature of telecommunications networks with their inherently complex elements can pose a difficult challenge. Reliability metrics need to address network design and operations, service delivery, element functions, and provide guidance on development of Service Level Agreements (SLA).

Two traditional reliability measures – Mean Time Between Failures (MTBF) and Availability – can be applied only to elements with two states: Up State (Element is Functioning) and Down State (Element is Failed). Availability is a steady state metric defined as:

$$\boldsymbol{A = MTBF/(MTBF + MTTR)}$$

where MTTR is the Mean Time to Repair, and Unavailability:

$$\boldsymbol{U = 1 - A = MTTR/(MTTR + MTBF)}$$

For systems with partial failures, the telecommunication industry developed two reliability measures: Defects per Million (DPM) and Mean Time Between Outages (MTBO), which incorporate the impact of failures. DPM is a generalization of Unavailability where downtime of each failure is weighted by the number of customers impacted. DPM is calculated for a given period of time T as a fraction of the total weighted downtime during that period multiplied by 1,000,000 [ATIS-0100008].

MTBO is an extension of MTBF – it is a field metric that removes the main limitation of practical application of the field MTBF where only failures leading to Field Replacement Unit (FRU) are counted. MTBO counts all customer impacting failures, including software reboots that do not result in element replacement.

The impact of failures in modern systems for voice and data transmission (e.g., IP routers or a Radio Network Controller) as well as mobility and wire-line communication networks with hierarchical design increases progressively with the hierarchical level. For example, a silent failure of just one component in a router switch fabric (top hierarchical level) results in unacceptable packet loss across all router line cards (bottom hierarchical level) until the failure is detected and the router is taken out of service. As described in clause 5, DPM and MTBO have limitations that prohibit reliability assessments in the design phase of such systems. The intent of this document is to define a new metric that could be applied to reliability assessment of such systems at the design stage.

The proposed metric is an extension of the MTBF metric – *Impact Weighted MTBF (IW-MTBF)* – that combines MTBF values for all hierarchical levels of a given network element or network segment by weighting MTBF for each level by its respective impact on failures. The scope of this document is restricted to the definition of this new metric and the derivation of illustrative examples to demonstrate its power and usage. These illustrations provide guidance on estimating the reliability of complex systems in the design phase via IW-MTBF and then comparing this value with the actual field reliability via MTBO. The development of the necessary measurement capabilities needed to collect data for metric estimation is for further study.

2 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

[ATIS-0100008] – ATIS-0100008.2007 (R2012), *Defects Per Million (DPM) Metric for Transaction Services such as VoIP*.[1]

[ATIS-0100030] ATIS-0100030.2012, *Mean Time Between Outages – A Metric for Assessing Production Failure Rates in IP Routers*.[2]

3 Definition

3.1 Impact Weighted MTBF: The MTBF for a complex hierarchical system with redundancy is broadly defined as the reciprocal of the sum of the individual failure rates of each hierarchical level (reciprocal of level MTBF) weighted respectively by the number of elements in the level impacted by the failure. A formal mathematical definition is provided in clause 7.

3.2 Silent Failure: A failure in a network element (e.g., router) is referred to as a silent failure if it is not detected by the network's fault management system.

4 Acronyms & Abbreviations

CP	Call Processor
DPM	Defects per Million
FCC	Fabric Card Chassis
FRU	Field Replacement Unit
IP	Interface Processor
LC	Line Card
LCC	Line Card Chassis
LTE	Long Term Evolution
MSN	Mobility Switch Node
MTBF	Mean Time Between Failure
MTBO	Mean Time Between Outage
PE	Provider Edge Router
PP	Primary Processor
RNC	Radio Network Controller
RP	Route Processor
SF	Switch Fabric
SLA	Service Level Agreement
SPOF	Single Point of Failure
SP	Service Provider

[1] This document is available from the Alliance for Telecommunications Industry Solutions (ATIS), 1200 G Street N.W., Suite 500, Washington, DC 20005 < https://www.atis.org/docstore/product.aspx?id=26794 >.

[2] This document is available from the Alliance for Telecommunications Industry Solutions (ATIS), 1200 G Street N.W., Suite 500, Washington, DC 20005 < https://www.atis.org/docstore/product.aspx?id=26774 >.

UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
VoIP	Voice over IP

5 Reliability Impacts on Complex Hierarchical Systems – An Introduction

Modern day Service Provider (SP) network architectures are continuously evolving to provide a growing and complex range of telecommunications services to their customers. Traditional Voice and Data services are combined with increasing demands for multimedia content delivery to end devices over wireless and wired networks. In this environment, SP network architectures have to deploy the following:

- *Access Technologies* – These include mobility/wireless as well as cable and DSL broadband access networks. It should be noted that wireless handheld device applications represent the most rapid growth of telecommunications traffic for SPs.
- *Backhaul Technologies* – These represent the interconnection between access networks and the large core backbones for SPs. Typical technologies are Gigabit Ethernet as well as metropolitan SONET Rings.
- *Core Backbone Technologies* – The most common backbone technology deployed today is based on IP routers running on Multi-Protocol Label Switching (MPLS) protocols.

The breadth and diversity of network types requires highly complex network element systems interacting with one another. Multiple equipment suppliers with their often proprietary designs add to the complexity.

From a reliability perspective, the evolving nature of telecommunications networks with their inherently complex elements can pose a difficult challenge. Reliability metrics need to address several questions:

- *From a network perspective*:
  - Is the network functioning in a reliable manner?
  - Does the network deliver the service to a customer in an acceptable manner?
- *From an element perspective*:
  - Are the network elements as reliable as advertised? This represents an SP point of view.
  - How can appropriate guarantees be captured in Service Level Agreements (SLA)? This is an equipment supplier point of view.

No single reliability metric can satisfactorily answer all of these questions. SPs have typically examined the reliability questions in a variety of ways. When appropriate, traditional reliability metrics have been invoked – examples include Availability, Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), etc. These metrics provide useful guidance but they also have limitations. For example, MTBF assumes total replacement of a failed element whereas many modern routers simply “Reboot” after a failure event.

SPs have also engaged in the development of tailored metrics that examine very specific aspects of telecommunications. Examples include the following:

- *Defects per Million (DPM)* – Given that daily service transactions (e.g., Voice over IP calls) number in the tens of millions, this metric provides an insight into service transaction success rates [ATIS-0100008]. DPM is a linear metric in the sense that Total DPM is a sum of DPM contributions caused by component failures. This property permits the application of the DPM metric not only in production networks but also for design evaluation before production.
- *Mean Time Between Outages (MTBO)* – This is a modification of the MTBF metric in that it counts all customer impacting failures including software reboots [ATIS-0100030]. MTBO is a field metric that removes the main limitation of practical application of the field MTBF where only failures leading to Field Replacement Unit (FRU) are counted. In addition, MTBO includes the definition of a unit in which the failure

impact is counted. That enables the application of MTBO to a uniform set of network elements with total and partial failures [ATIS-0100030]. For example, for a set of access or Provider Edge (PE) routers, such a unit is defined as the access line card. Then the failure impact of the entire router is the total number of access line cards on that router. Note that in contrast to DPM, MTBO is an aggregate measure that can be applied only in production conditions.

These specialized reliability metrics also have their limitations which are evident when tackling the reliability aspects of increasingly complex network element systems that are being deployed to support the growth of telecommunications services. For instance, the DPM metric involves the use of Downtime that is weighted by the failure impact. In addition, DPM does not shed sufficient insight into the contribution of the equipment supplier – it can be skewed by a long restoration time as a result of SP intervention. As stated above, MTBO can only be applied in production networks – it cannot be applied for design evaluation of modern systems for voice and data transmission (e.g., IP routers or a Radio Network Controller) as well as mobility and wire-line communication networks with hierarchical design. The elements at the higher levels of a hierarchy of such systems usually incorporate redundancy[3]. A silent failure in the top hierarchical level often results in downtime for the entire system resulting in significant – and unacceptable – customer impacts.

This is the motivation for deriving a new metric to solve this problem. Hierarchical systems – non-degradable redundancy at the upper hierarchical levels having multiple working and failure modes – are described in clause 6. The new metric – *Impact Weighted MTBF (IW-MTBF)* that incorporates impact of failures at higher hierarchical levels – is defined in clause 7. Examples illustrating the use of this metric are provided in clause 8.

6 Complex Hierarchical Systems

Four relatively simple examples that demonstrate wide presence of hierarchical systems in modern telecommunications are described in this clause.

6.1 Single Chassis IP Router

A single chassis IP router (Figure 1) typically has a two-level hierarchical architecture. Level 1 is represented by N line-cards. A line-card is a single point failure. Level 2 is represented by the following two redundant subsystems:

- Two route processors (RPs) in active-standby mode
- Switch fabric interconnecting line-cards and RPs.

Failure of active RP without switchover to standby unit impacts all N line-cards. Switch fabric consists of $M+1$ units which have $M+1$ or M-out-of-$M+1$ redundancy. In the first case, M units are active and one additional unit is standby. In the second case, all $M+1$ units are active. M units provide full interconnection bandwidth. Failure of two units or undetectable (silent) failure of one active unit will cause unacceptable packet loss impacting all N line cards.

[3] The elements in such systems typically include a variety of components, possibly from multiple equipment suppliers.

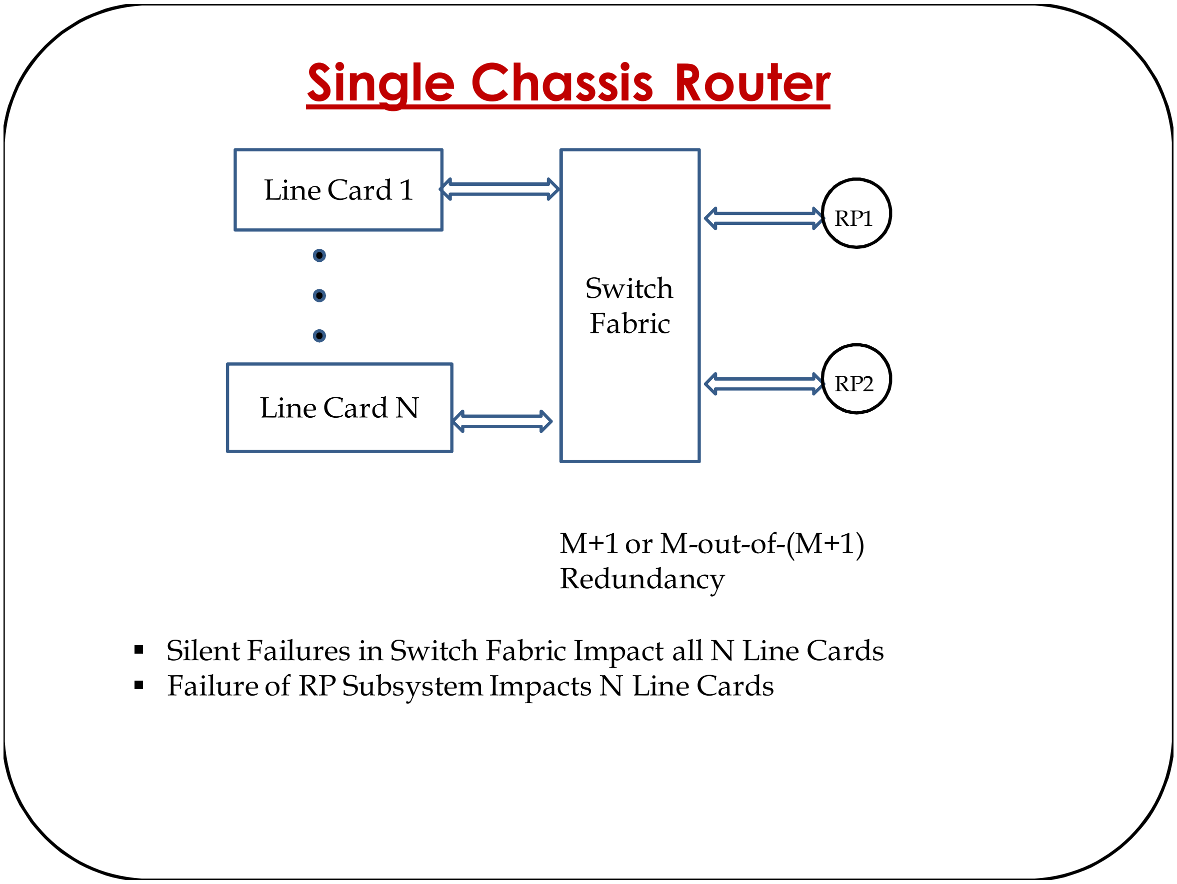

Figure 1 - Single Chassis Router

6.2 Multi-Chassis IP Router

A multi-chassis IP router (Figure 2) consists of L line-card chassis (LCCs). Each LCC has K line-cards (level 1) and two RPs (level 2) similar to the single-chassis router. Level 3 is represented by fabric card chassis (FCC) that consists of $M+1$ planes interconnecting all intra- and inter-chassis line cards and RPs (Figure 2). M planes provide full interconnection bandwidth. Failure of two planes or undetectable (silent) failure of one active plane will cause unacceptable packet loss impacting all $N = KL$ line cards. However, failure of active RP without switchover to standby unit in one LCC impacts only K line-cards in that LCC.

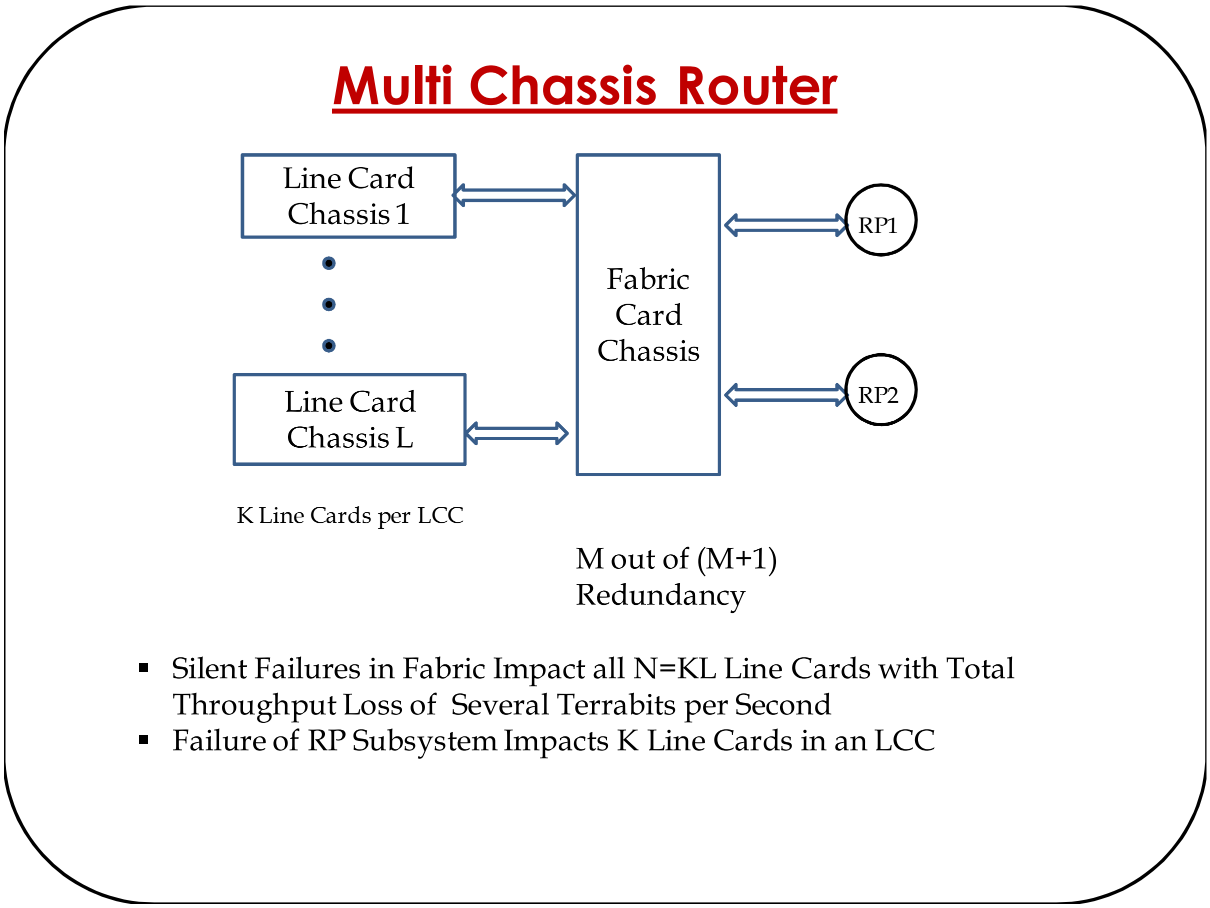

Figure 2 - Multi-Chassis Router

6.3 Radio Network Controller

RNC has a two-level hierarchical architecture (Figure 3). Level 1 is represented by N active call processors (CPs). A detectable failure of one active CP triggers redistribution of calls to $N-1$ remaining CPs without any loss. Undetectable (silent) failure of one active CP or failure of two or more CPs causes loss of calls. Level 2 is represented by the following three redundant subsystems operating in active-standby mode:

- Two primary processors (PP).
- Two interface processors (IP).
- Two switch fabric (SF) units.

Failure of active unit without switchover to standby unit in any level 2 subsystem impacts all CPs.

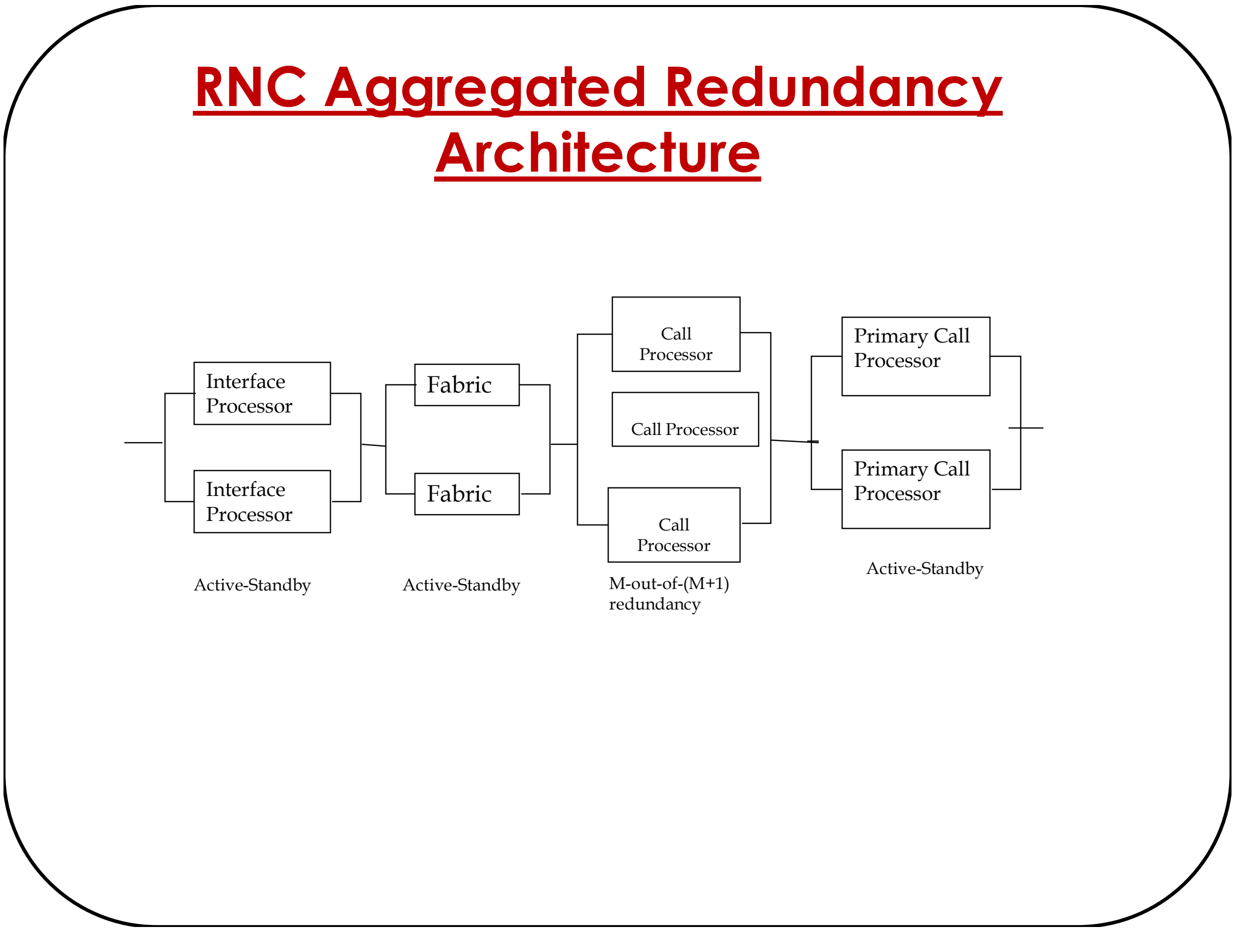

Figure 3 - RNC Architecture

6.4 Segment of 4G LTE Network

4G LTE (Long Term Evolution) networks have hierarchical designs, where elements at the upper levels of the hierarchy incorporate redundancy. To illustrate such a hierarchical design consider a network segment (Figure 4) where traffic originated at Evolved NodeBs (eNB) – which is essentially a 4G base station – is consecutively aggregated first at the Mobility Telephone Switch Office (MTSO) aggregation routers and then at the MTSO Provider Edge routers (PE) where routers are deployed in pairs for redundancy at both aggregation levels. This network segment consists of three subsystems with increasing hierarchical levels $i = 1,2,3$ corresponding to a set of eNBs combined with their cell site router, aggregation and PE routers respectively. Note that each router has an hierarchical architecture as described in 6.1 and 6.2 above. Subsystem at level $i \geq 2$ is redundant as it consists of two routers. Only *traffic-impacting* failures which occur due to the limitations of the adopted redundancy are counted. Let N be the number of eNBs in subsystem 1. The failure impact of an element in subsystem 1 is 1. However, the failure impact of the highest-level subsystem 3 is N because it impacts all eNBs in subsystem 1. The failure impact of a subsystem at level 2 is measured by the number of eNBs $K < N$ in subsystem 1 that are connected to it.

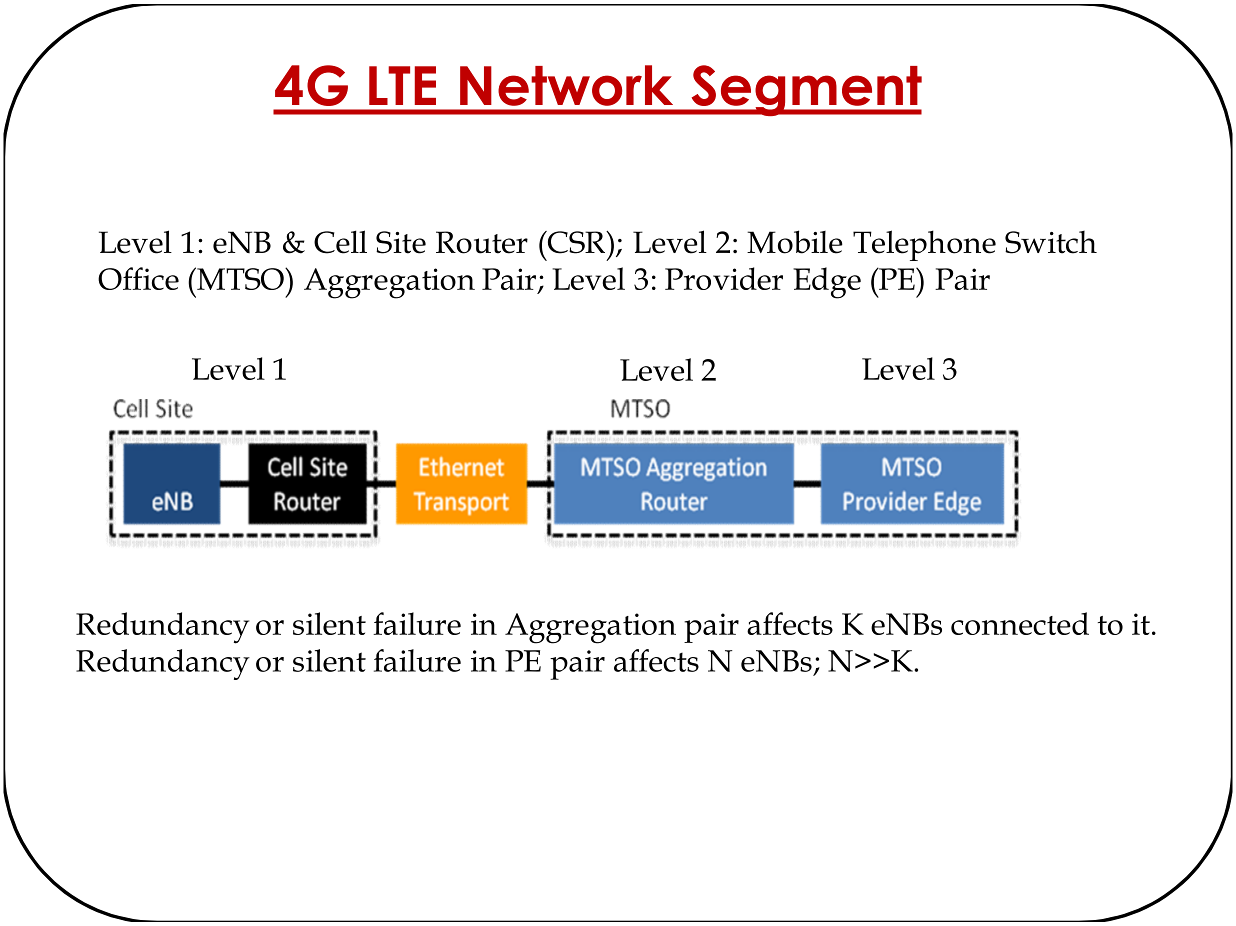

Figure 4 - 4G LTE Segment Architecture

7 Definition of Impact Weighted MTBF

Consider a system that consists of three subsystems with increasing hierarchical levels $i = 1,2,3$. In general, all subsystems are redundant. Only *traffic-impacting* failures which occur due to the limitations of the adopted redundancy are counted.

Let N be the number of elements in subsystem 1. The failure impact of an element in subsystem 1 is:

- 0 – If the redundancy protects against that failure.
- 1 – Otherwise.

However, the failure impact of the highest-level subsystem is N because it impacts all elements in subsystem 1. The impact of a failure of a subsystem at level 2 is the number of elements K in subsystem 1 that are connected to it. For subsystem $i = 1,2,3$, the mean time until the first customer impacting failure starting at a state where all active and redundant elements of subsystem i are "up", is referred to as level i uptime U_i. Then the IW-MTBF metric is defined as

$$\boldsymbol{IW\_MTBF} = (\boldsymbol{1}/\boldsymbol{U_1} + \boldsymbol{K}/\boldsymbol{U_2} + \boldsymbol{N}/\boldsymbol{U_3})^{-1} \qquad (1)$$

Note that level-2 subsystem may consist of several components like in the case of single chassis router (two components – a pair of RPs and SW) or RNC (three components – three pairs of IPs, MPs, and fabrics). For component $j = 1, 2, \ldots, m$, the mean time until the first customer impacting failure at a state where all active and redundant elements of component j are "Up", is referred to as component j Uptime u_{2j}. Let the failure of each component impact the same number of elements K in level-1 subsystem. Then level-2 Uptime is calculated as

$$\boldsymbol{U_2} = \left\{ \sum_{j=1}^{m} \boldsymbol{1}/\boldsymbol{u_{2j}} \right\}^{-1} \qquad (2)$$

Level-3 uptime is similarly calculated in case of several components and failure of each component impacts the same number of elements N in level-1 subsystem. It is not difficult to generalize this example to a hierarchy with a greater number of levels.

8 Impact Weighted MTBF – Practical Examples

This clause illustrates the benefits of the IW-MTBF metric for hierarchical systems considered in clause 6 through numerical example using for calculation of level-2 Uptime and IF-MTBF equations (2) and (1), respectively. The time is measured in hours.

8.1 Single Chassis Router

Consider a router in Figure 1 with $K = 10$ line cards carrying customer traffic. Table 1 provides reduction in IW-MTBF in comparison with line-card (LC) MTBF due to failures of level-2 subsystem consisting of two redundant components: RP and SF. Level-2 uptime is calculated in Table 2 using given uptimes for RP and SF. The expectation is that failures of RP and SF components should have minimal impact on line cards. In our example, it is indeed the case when LC-MTBF is low (50,000 hours). However for LC-MTBF=150,000, the reduction of 25% is quite large. The only way to have a smaller reduction is to increase the uptime for RP and SF components.

Table 1 - IW-MTBF Reduction in Comparison with LC-MTBF

Reduction %	**10%**	**18%**	**25%**
IW-MTBF	44,944	81,633	112,150
LC-MTBF	50,000	100,000	150,000

Table 2 - Uptime for RP, SF, and Level 2

Component	RP	SF	Level 2
Uptime	10,000,000	8,000,000	4,444,444

Consider a set of routers with architecture given in Figure 1 where RP and SW subsystems and the number K of line cards are the same for all routers. Then MTBO measured in production for this set of routers would be a field estimate of IW-MTBF where the latter was calculated based on expected uptime of RP and SW components.

8.2 Multi-chassis Router

Consider a router with $L = 6$ line-card chassis (LCC), with 15 line cards per each LCC $(K = 16)$ and the total number of line cards $N = 6 \times 15 = 90.$ Each LCC has two RPs and six LCCs are interconnected by fabric. Table 3 provides reduction in IW-MTBF in comparison with line-card LC-MTBF=300,000 hours due to failures of level-2 RP-subsystem and level-3 fabric subsystem. The IW-MTBF and respective reduction are calculated for RP-Uptime=100,000,000 hours. Note that FCC-Uptime has major impact on Reduction. Reduction decreases from 98% for FCC-Uptime=500,000 hours to 21% for FCC-Uptime=125,000,000 hours. However, even 21% Reduction is not low enough that emphasizes the importance of significantly high FCC-Uptime in multi-chassis router.

Table 3 - G-Uptime Reduction in Comparison with LC-MTBF

Router	A	B	C
Reduction %	21%	37%	98%
IW-MTBF	237,906	189,274	5,450
FCC-Uptime	125,000,000	50,000,000	500,000

Consider a set of multi-chassis routers with architecture given in Figure 2 where RP and FCC subsystems as well as the number of chassis L and the number N of line cards are the same for all routers. Then MTBO measured in production for this set of routers would be a field estimate of IW-MTBF where the latter was calculated based on expected uptime of RP and FCC subsystems.

Routers may have the same line cards and RPs in single-chassis and multi-chassis configurations. However, their IW-MTBF values will be generally different for the following two reasons. First, the FCC is more complex than SF in single-chassis routers that may result in lower FCC-Uptime. Second, the impact of FCC failure in multi-chassis routers is generally larger than the impact of SW failure in single-chassis routers. Therefore, the MTBO calculation for the combined set of single- and multi-chassis routers would likely underestimate the IW-MTBF for single chassis routers and overestimate the IW-MTBF for multi-chassis routers.

In addition, the IP backbone may have a hierarchical design with largest multi-chassis routers at the top of the hierarchy. In such a case, actual failure impact depends on the router place in the hierarchy. Hence, the existing formula for MTBO calculation based on the number of affected line cards can be applied only to the set of routers at the same hierarchical level.

8.3 Radio Network Controller

Consider an RNC with $K = 8$ call processors (CPs). Table 4 provides reduction in IW-MTBF in comparison with CP-subsystem uptime (CP-Uptime) due to failures of level-2 subsystem caused by redundancy failures in MP, IP or SF component in level 2. Uptimes for MP, IP, and SF along with Level 2 uptime calculated using (2) are provide in Table 5. The Reduction is quite large (in the range 47% - 57%) that indicates that the uptime for level 2 components is not large enough.

Table 4 - IW-MTBF Reduction in Comparison with CP-Uptime

Reduction %	47%	53%	57%
IW-MTBF	423,529	473,684	514,286
CP-Uptime	800,000	1,000,000	1,200,000

Table 5 - Uptime for MP, IP, SF, and L2-Uptime

Component	MP	IP	SF	Level 2
Uptime	20,000,000	18,000,000	30,000,000	7,200,000

Consider a set of RNCs with architecture given in Figure 2 and the same number of CPs. Then MTBO measured in production using one CP as a unit of failure impact would be a field estimate of IW-MTBF where the latter was calculated based on expected uptime of IP, MP and fabric components. The impact of RNC failure can be measured more granularly by the number of affected base stations (nodeBs). Then IW-MTBF and its MTBO estimate in production must be compared with nodeB-Uptime.

8.4 Access Segment of LTE Network

Consider a network segment in Figure 4 with parameter values $N = 90$ and $K = 15.$ Table 6 provides reduction in IW-MTBF in comparison with eNB uptime of 10,000 hours due to failures of Aggregation routers (level-2 subsystem) and PE routers (level-3 subsystem). As expected, the reduction increases as Aggregation-Uptime and PE-Uptime decreases.

Table 6 - G-Uptime Reduction in Comparison with eNB-Uptime

Reduction %	**14%**	**25%**	**40%**
G-Uptime	8,562	7,485	5,981
Aggregation-Uptime	2,000,000	1,000,000	500,000
PE-Uptime	10,000,000	5,000,000	2,500,000

Consider an access segment of LTE (4G) network with interconnection architecture shown in Figure 4 where routers are identical in terms of their architecture and vendor inside each of two sets of Aggregation and PE routers. In general, there could be two different vendors for Aggregation and PE routers respectively. By selecting an eNB (evolved node B) as an impact unit for failure in Aggregation and PE levels, the MTBO measured in a production network with architecture in Figure 4 will be an estimate of IW-MTBF.

9 Concluding Remarks

Examples in clauses 8.1 through 8.4 demonstrate a fairly broad application of the new metric IW-MTBF that incorporates the hierarchical structure of network elements and segments. The application of IW-MTBF requires knowledge of the Uptime for redundant subsystems at the upper hierarchical levels. For sufficiently large coverage factor exceeding 99%, the Uptime of a redundant system is very close to mean time between silent failures (MTBSF). Thus the knowledge of MTBSF is critical for application of IW-MBTF. For a brand new system, MTBSF can be provided only by its vendor similar to predicted MTBF for system's component. MTBSF can be also measured in production but the observation interval must be fairly large – e.g., 18-24 months as silent failures are expected to be rare.