SDN EPC GATEWAYS COST MODELING

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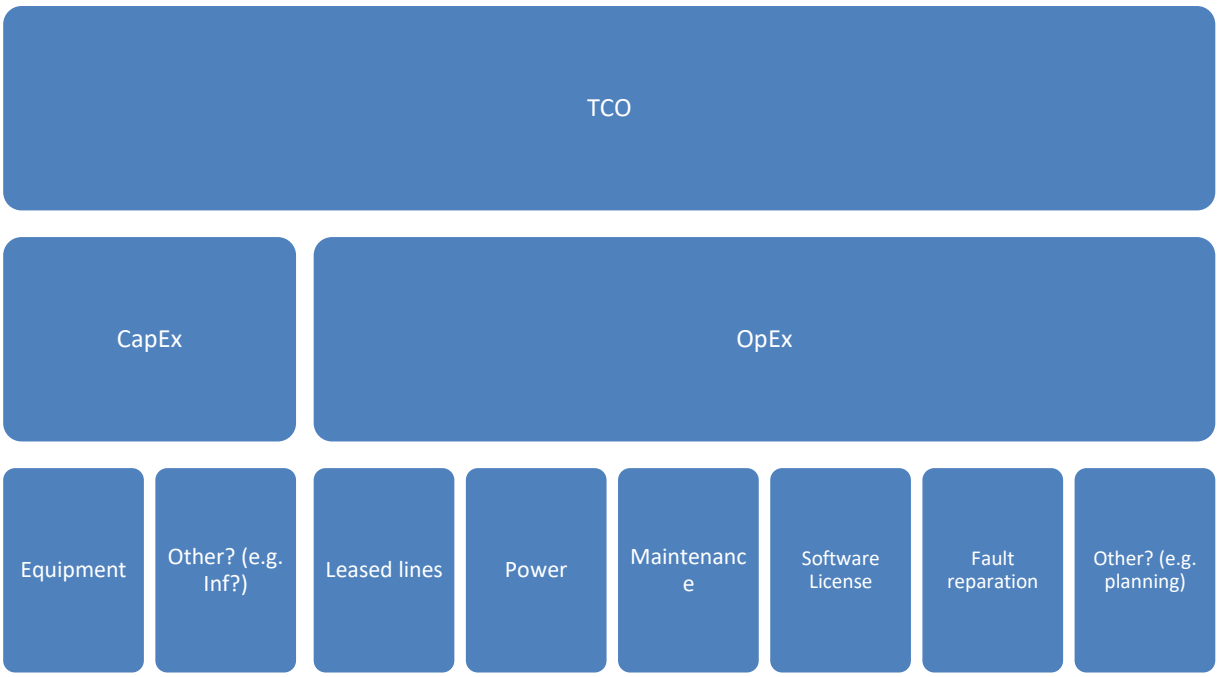
Given a network lifetime T, compare the cost of a classic LTE EPC and an SDN-enabled LTE EPC.

Total Cost of Ownership (TCO) is defined as the sum of CapEx (costs which suffer depreciation) and OpEx.

The costs included in this cost model are:



Models

Three EPC models are considered:

- Legacy: It corresponds to the actual EPC architecture with current gateways.
- SDN: It corresponds to an EPC architecture with all the nodes are SDN enabled. This means that each node is a “u” entity (so-called NE), which takes care of the user data, and there is a central controller “c” which takes care of all the signalling data. In this scenario, all the “c” entities are placed in the cloud platform. In this scenario, OF traffic flows between cloud and transport network.

- Cloud: This scenario considers all the gateways virtualized as software and running in the cloud, i.e., both user data and control are deployed in the cloud.

Cloud Platform Alternatives

There can be two alternative use-cases in case a cloud platform is needed either to host gateway controllers, i.e., SDN model, or to host virtual gateway instances, i.e., Cloud model.

- The cloud platform is owned by the operator
- The cloud platform is leased by the operator.

Gateway Resilience

Resilience is considered only for the EPC gateways, where a 1:1 protection scheme with hot standby is considered in order to achieve a negligible service interruption. The backup gateway is assumed to synchronize its configuration with the working gateway.

A leased protected infrastructure is considered, which assumes that (link resilience) is already provided. In case of a leased cloud platform, a resilient cloud slice is assumed. This means that no protection mechanisms for the leased cloud resources need to be enforced by the operator.

The following failure types are considered:

- Legacy: physical and logical failures of gateways
- SDN: physical and logical failures of SDN NEs / logical failures of SDN controllers
- Cloud: logical failures of virtual gateways

Resilience provisioning for the three models can be illustrated at each figure respectively:

a) Legacy: resilience in this model considers that all gateways are fully duplicated, which covers both logical and physical failures of gateways. The backup gateways are assumed to be active, where each backup gateway is frequently receiving state synchronization update from its respective working gateway.

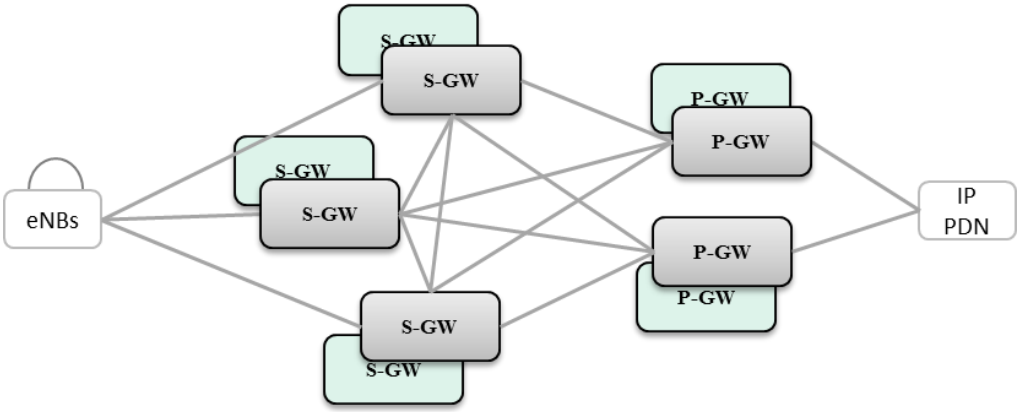


Figure 1 Legacy Gateways with Resilience

b) SDN: resilience in this model considers that the controller can cover both physical and logical failures of SDN NEs, as well as controller failures. Hence, duplication is needed for the SDN network elements as well as for the controller software instances in the cloud.

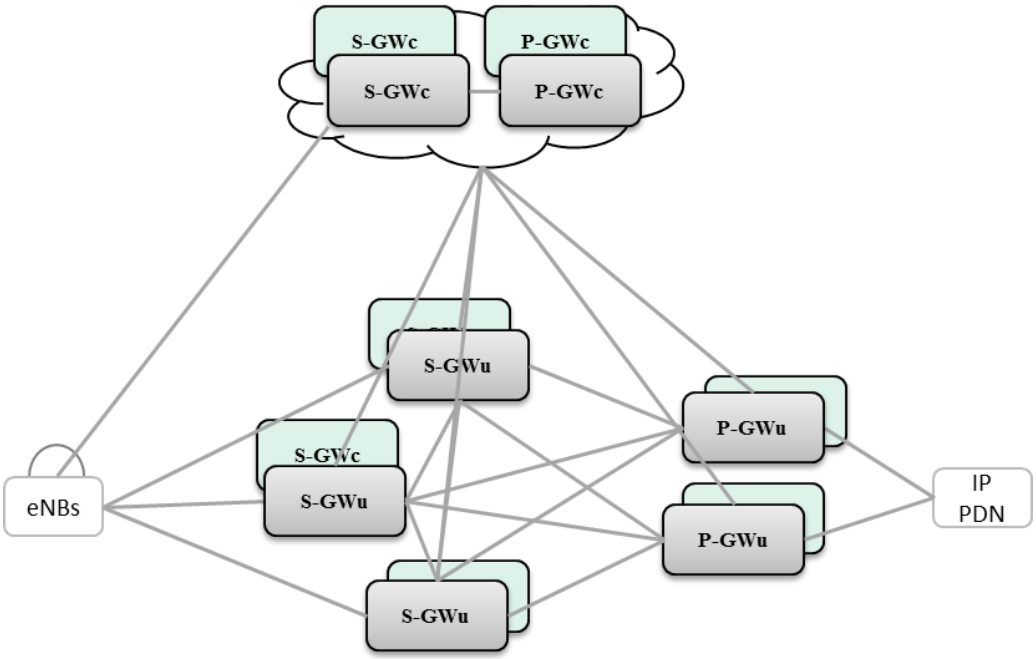


Figure 2: SDN-enabled Gateways with Resilience

c) Cloud: resilience in this model considers the logical failures of the virtual gateway instances. Therefore, the gateway instances need to be duplicated.

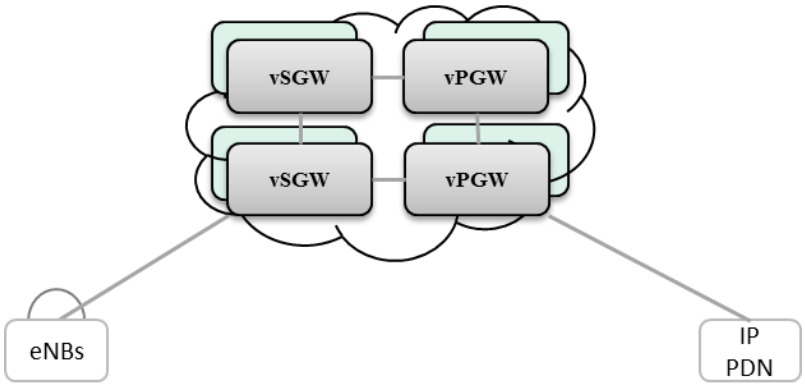


Figure 3: Cloud-based Gateways with Resilience

Cost modelling

Let us model the cost for the extreme cases of the three models: legacy, SDN and Cloud, considering the following four scenarios:

- Unprotected, Own cloud
- Protected, Own cloud
- Unprotected, Leased cloud
- Protected, Leased cloud

Let us define as N the number of nodes, which can be SDN-enabled.

Let us define the gateways' traffic as the sum of the data-plane (tr_u) and LTE signalling (tr_s). In case of SDN-enabled gateways, (tr_OF) is defined as the OpenFlow traffic between SDN NEs and SDN controllers. Additionally let us define (tr_sy) for the state synchronization traffic between the working and the backup gateways in case of resilience.

1. **CapEx**: Any cost which suffers depreciation. In this case, we consider only gateway costs, since infrastructure is assumed to be leased (OpEx).
   1.1. **Equipment:** Let us model the equipment cost of each scenario
      1.1.1. **Unprotected, Own cloud Scenario**
      - Legacy: the equipment cost is the sum of all the gateways. Assuming a cost of c_g_i € for the gateway *i* which depends on the data and signalling traffic.
      - SDN: the equipment cost is the sum of the cost c_ne_i € of the SDN-enabled nodes. Furthermore, the cost of the controllers ($c_{controllers}$) should be added. Each controller cost ($c_{controller}$) can be defined as a fixed cost for its software (c_{SW}) and a cloud hardware cost (c_{HW}), required to host the controller, that is proportional to the signalling and OpenFlow traffic.
      - Cloud: the cloud cost could be dimensioned according to the virtual gateways. The virtual gateway costs can be defined as a fixed cost for its software (c_{SW}) and a cloud hardware cost ($c_{cloudHW}$), required to host the virtual gateway, that is proportional to data and signalling traffic.

	legacy	SDN	Cloud
Equipment	$\sum_{i=1}^{N} c\_g_i \ (tr_u + tr_s)$	$\sum_{i=1}^{N} c\_ne_i(\ tr_u + \ tr_{OF}) + c_{controllers}\ (sw, cloud)$ where each $c_{controller} = c_{SW} + c_{cloudHW}(tr_s + tr_{OF})$	$c_{virtualGWs}\ (sw, cloud)$ where each $c_{virtualGW}$ = c_{SW}+ $c_{cloudHW}(\ tr_u + tr_s)$

1.1.2. **Protected, Own cloud Scenario**

- Legacy: in order to have resilient gateways, a 1:1 protection scheme is considered: all gateways are fully duplicated and hence, the cost is doubled.
- SDN: the SDN-enabled nodes are duplicated. The controllers cost is multiplied by a factor *R* to represent the cost of resources needed for protection, where 1 < *R* ≤ 2.
- Cloud: The virtual gateways cost is multiplied by a factor *R* to represent the cost of resources needed for protection, where 1 < *R* ≤ 2.

	legacy	SDN	Cloud
Equipment	$2 * \sum_{i=1}^{N} c\_g_i \ (tr_u + tr_s)$	2* $\sum_{i=1}^{N} c\_ne_i(\ tr_u + \ tr_{OF}) + R * c_{controllers}\ (sw, cloud)$ where each $c_{controller} = c_{SW} + c_{cloudHW}(tr_s + tr_{OF} + \ tr_{sy})$	$R * \ c_{virtualGWs}\ (sw, cloud)$ where each $c_{virtualGW}$ = c_{SW}+ $c_{cloudHW}(tr_u + tr_s + tr_{sy})$

1.1.3. **Unprotected, Leased cloud Scenario**

- SDN: the cost of the SDN-enabled nodes and controllers' software are only considered as CapEx. Since the cloud platform is leased, it is considered as OpEx.
- Cloud: the cost of virtual gateways software only.

	legacy	SDN	Cloud
Equipment	$\sum_{i=1}^{N} c\_g_i \ (tr_u + tr_s)$	$\sum_{i=1}^{N} c\_ne_i(\ tr_u + \ tr_{OF})$ + $c_{controllers}\ (sw)$ where each $c_{controller} = c_{SW}$	$c_{virtualGWs}\ (sw)$ where each $c_{virtualGW}$ =c_{SW}

1.1.4. **Protected, Leased cloud Scenario**

- SDN: the cost of the SDN-enabled nodes and controllers' software are only considered as CapEx, multiplied by a protection factor R. Since the cloud platform is leased, it is considered as OpEx.
- Cloud: the cost of virtual gateways software only multiplied by a protection factor R.

	legacy	SDN	Cloud

Equipment	$2 * \sum_{i=1}^{N} c\_g_i \ (tr_u + tr_s)$	$2 * \sum_{i=1}^{N} c\_ne_i (\ tr_u + \ tr_{OF}) + R * \ c_{controllers} \ (sw)$ where each $c_{controller} = c_{SW}$	$R * \ c_{virtualGWs} \ (sw)$ where each $c_{virtualGW} = c_{SW}$

2. **OpEx**: Operational expenditures due to the operation of the network
   2.1. **Leased lines**: In the case that the operator uses leased lines, the cost should be considered as OpEx. It is defined as any leased physical connection between two locations (e.g. using optical fiber). The leased lines are assumed to be protected.
   2.1.1. **For All Scenarios**
   - Legacy: it is the sum of the cost c_l_i € of leased links. The link cost is proportional to the data and signalling traffic.
   - SDN: it is the sum of the following three link types:
     - There are *L_u* links used to carry data traffic to the SDN-enabled nodes with a cost c_lu_i €.
     - There are *L_c* links to carry signalling traffic to the controllers at the cloud with a cost c_lc_i €.
     - There are *L_OF* links to carry OF traffic between controllers at the cloud and the SDN-enabled nodes with a cost of c_lOF_i €.
   - Cloud: it is the sum of the cost c_lc_i € of the links used to carry data and signalling traffic to the virtual gateways at the cloud.

	legacy	SDN	Cloud
Leased lines	$\sum_{i=1}^{L} c\_l_i \ (tr_u + tr_s)$	$\sum_{i=1}^{L\_u} c\_lu_i \ (tr_u)$ + $\sum_{i=1}^{L\_c} c\_lc_i \ (tr_s)$ + $\sum_{i=1}^{L\_OF} c\_lOF_i \ (tr_{OF})$	$\sum_{i=1}^{L\_c} c\_lc_i \ (tr_u + tr_s)$

   2.2. **Power**: The power consumed by any equipment of the network and the power consumed by A/C used for cooling the equipment. The power is dependent on the traffic processing.
   2.2.1. **Unprotected, Own cloud Scenario**
   - Legacy: the power cost is proportional to the power consumed by each of the N nodes, which depends on the traffic supported by each node (p_g). It is multiplied by the cooling component cost factor of A/C (p_{acN}).
   - SDN: the power cost is also proportional to the power consumed by each SDN-enabled node (p_ne), which is multiplied by the cooling component cost factor of A/C (p_{acN}). On the other hand, the power consumed by the cloud hosting the controller should

be also considered ($p_{cloudHW}$), which is proportional to signalling and openFlow traffic. It is multiplied by the cooling cloud cost factor of A/C ($p_{acCloud}$). $p_{acCloud} > p_{acN}$.

- Cloud: the power consumed by the cloud hosting the controllers ($p_{cloudHW}$), proportional to data and signalling traffic, multiplied by the cooling cost factor of A/C ($p_{acCloud}$).

	legacy	SDN	Cloud
Power	$p_{acN} * \sum_{i=1}^{N} p\_g_i \ (tr_u + tr_s)$	$p_{acN} * \sum_{i=1}^{N} p\_ne_i \ (tr_u + tr_{OF}) + p_{acCloud} * p_{cloudHW}(tr_s + tr_{OF})$	$p_{acCloud} * p_{cloudHW}(tr_u + tr_s)$

2.2.2. **Protected, Own cloud Scenario**

- Legacy: the power cost is proportional to the power consumed by each of the N nodes, which depends on the traffic supported by each node (p_g) and the power of the backup gateways (p_b) which only depends on the synchronization frequency. Both multiplied by the cooling cost factor of A/C (p_{acN}).
- SDN: the power cost is also proportional to the power consumed by each SDN-enabled node (p_ne). No need for synchronization between the SDN nodes as the configuration state is synchronized between the controllers. The power can be scaled by the protection factor R.
- Cloud: the power consumed by the cloud hosting the controller ($p_{cloudHW}$) multiplied by the cooling cost factor of A/C ($p_{acCloud}$) and protection factor R.

	legacy	SDN	Cloud
Power	$p_{acN} * \sum_{i=1}^{N} p\_g_i \ (tr_u + tr_s) + p_{acN} * \sum_{i=1}^{N} p\_b_i \ (tr_{sy})$	$p_{acN} * \sum_{i=1}^{N} p\_ne_i \ (tr_u + tr_{OF}) + p_{acCloud} * R * p_{cloudHW}(tr_s + tr_{OF} + tr_{sy})$	$p_{acCloud} * R * p_{cloudHW}(tr_u + tr_s + tr_{sy})$

2.2.3. **Unprotected, Leased cloud Scenario**

- No explicit power costs, when leasing the cloud

	legacy	SDN	Cloud

Power	$p_{acN} * \sum_{i=1}^{N} p\_g_i \ (tr_u + tr_s)$	$p_{acN} * \sum_{i=1}^{N} p\_ne_i \ (tr_u + tr_{OF})$	0

2.1.4. **Protected, Leased cloud Scenario**

- No explicit power cost, when leasing the cloud

	legacy	SDN	Cloud
Power	$p_{acn} * \sum_{i=1}^{N} p\_g_i \ (tr_u + tr_s) + p_{acN} * \sum_{i=1}^{N} p\_b_i \ (tr_{sy})$	$p_{acN} * \sum_{i=1}^{N} p\_ne_i \ (tr_u + tr_{OF})$	0

2.3. **Maintenance**: It is the continuous process to survey, check, clean all network elements and assure that they function as expected. This process is done by technicians visiting regularly all equipment locations. The number of technicians depends on the number and size of nodes as well as on the required maintenance. The maintenance of the backup gateways in the α=0% scenario, is considered to be done in parallel with the working one and therefore it does not add significant cost.

2.3.1. **Unprotected, Own cloud Scenario**

- Legacy: maintenance cost is proportional to the number of nodes and the maintenance cost associated to each one (*m_g*).
- SDN: the maintenance cost is also proportional to the maintenance cost of each SDN-enabled node (m_ne). Furthermore, the maintenance cost of the cloud ($m_{cloudHW}$) should be added.
- Cloud: The maintenance cost is the cost associated to the maintenance of the cloud ($m_{cloudHW}$).

	legacy	SDN	Cloud
Maintenance	$\sum_{i=1}^{N} m\_g_i$	$\sum_{i=1}^{N} m\_ne_i + m_{cloudHW}(tr_s + tr_{OF})$	$m_{cloudHW}(tr_u + tr_s)$

2.3.2. **Protected, Own cloud Scenario**

- Legacy: maintenance cost is proportional to the number of nodes (now *2N*) and the maintenance cost associated to each one (*m_g*).

- SDN: the maintenance cost is also proportional to the maintenance cost of each SDN-enabled node (m_ne). Furthermore, the maintenance cost of the cloud (m_{cloud}) should be added, multiplied with a protection factor R.
- Cloud: The maintenance cost is the cost associated to the maintenance of the cloud (m_{cloud}).

	legacy	SDN	Cloud
Maintenance	$\sum_{i=1}^{2N} m\_g_i$	$\sum_{i=1}^{2N} m\_ne_i + R * m_{cloudHW}(tr_s + tr_{OF} + tr_{sy})$	$R * m_{cloudHW}(tr_u + tr_s + tr_{sy})$

2.3.3. **Unprotected, Leased cloud Scenario**

- The difference with respect the unprotected, own cloud scenario, is that no cloud maintenance cost should be considered and hence, the costs of each scenario are:

	legacy	SDN	Cloud
Maintenance	$\sum_{i=1}^{N} m\_g_i$	$\sum_{i=1}^{N} m\_ne_i$	0

2.3.4. **Protected, Leased cloud Scenario**

- The difference with respect the protected, own cloud scenario, is that no cloud maintenance cost should be considered and hence, the costs of each scenario are:

	legacy	SDN	Cloud
Maintenance	$\sum_{i=1}^{2N} m\_g_i$	$\sum_{i=1}^{2N} m\_ne_i$	0

2.4. **Software license upgrades**: Any software with a license should be upgraded, based on the license agreement. The software upgrade cost is proportional to the number of software licenses. The cost of installation and configuration is not included.

2.4.1.**Unprotected, Own cloud Scenario**

- Legacy: software licence costs are proportional to the number of nodes (*N*) and the license cost for each one (s_g).
- SDN: the software licence costs are the sum of the licenses of each SDN-enabled node (s_ne) and the licenses of all required controllers (s_{ctrs}). The licenses for the cloud operation (s_{cloud}) should be added.
- Cloud: software licence costs are the sum of the licenses of all required virtual gateways (s_{vgws}) and the licenses for the cloud (s_{cloud}).

	legacy	SDN	Cloud
Software License	$\sum_{i=1}^{N} s\_g_i$	$\sum_{i=1}^{N} s\_ne_i + s_{ctrs} + s_{cloud}$	$s_{vgws} + s_{cloud}$

2.4.2.**Protected, Own cloud Scenario**

- Legacy: software licence costs are proportional to the number of nodes (now 2*N*) and the license cost for each one (s_g).
- SDN: the software licence costs are the sum of the licenses of each SDN-enabled node (s_ne) and the licenses of all required controllers (s_ctrs) multiplied with a protection factor R. The licenses for the cloud operation (s_{cloud}) should be added.
- Cloud: software licence costs are the sum of the licenses of all required virtual gateways (s_{vgws}) multiplied by a protection factor R and the licenses for the cloud operation (s_{cloud}).

	legacy	SDN	Cloud
Software License	$\sum_{i=1}^{2N} s\_g_i$	$\sum_{i=1}^{2N} s_{ne_i} + R * s_{ctrs} + s_{cloud}$	$R * s_{vgws} + s_{cloud}$

2.4.3. **Unprotected, Leased cloud Scenario**

- The difference of this case with respect to the unprotected, own cloud scenario is that the software license cost of the cloud should not be considered.

	legacy	SDN	Cloud
Software License	$\sum_{i=1}^{N} s\_g_i$	$\sum_{i=1}^{N} s\_ne_i + s_{ctrs}$	s_{vgws}

2.4.4. **Protected, Leased cloud Scenario**

- The difference of this case with respect the protected, own cloud scenario is that the software license cost of the cloud should not be considered.

	legacy	SDN	Cloud
Software License	$\sum_{i=1}^{2N} s\_g_i$	$\sum_{i=1}^{2N} s_{ne_i} + R * s_{ctrs}$	$R * s_{vgws}$

2.5. **Fault reparation**: This is the cost related to the reparation of physical failures.

2.5.1.**Unprotected, Own cloud Scenario**

- Legacy: failure reparation costs are proportional to the number of nodes (*N*) and the failure reparation cost for each one (*r_g*).

- SDN: the failure reparation costs are the sum of the failure reparation cost of each SDN-enabled node (r_ne), and the failure reparation cost of the cloud hardware ($r_{cloudHW}$).
- Cloud: the failure reparation cost of the cloud ($r_{cloudHW}$).

	legacy	SDN	Cloud
Fault Reparation	$\sum_{i=1}^{N} r\_g_i$	$\sum_{i=1}^{N} r\_ne_i + r_{cloudHW}(tr_s + tr_{OF})$	$r_{cloudHW}(tr_u + tr_s)$

2.5.2.**Protected, Own cloud Scenario**

- Legacy: failure reparation costs are proportional to the number of nodes (now 2*N*) and the failure reparation cost for each one (*r_g*).
- SDN: the failure reparation costs are the sum of the failure reparation cost of each SDN-enabled node (r_ne), and the failure reparation cost of the cloud (r_{cloud}) multiplied by protection factor *R* which denotes the increase of the reparation of the protected cloud with respect the unprotected one.
- Cloud: the failure reparation cost of the cloud (r_{cloud}) multiplied by a factor *R* which denotes the increase of the reparation of the protected cloud with respect the unprotected one.

	legacy	SDN	Cloud
Fault Reparation	$\sum_{i=1}^{2N} r\_g_i$	$\sum_{i=1}^{2N} r\_ne_i + R * r_{cloudHW}(tr_s + tr_{OF} + tr_{sy})$	$R * r_{cloudHW}(tr_u + tr_s + tr_{sy})$

2.5.3. **Unprotected, Leased cloud Scenario**

- The difference of this case with respect the unprotected, own cloud scenario is that the protection costs of the cloud should not be considered.

	legacy	SDN	Cloud
Fault Reparation	$\sum_{i=1}^{N} r\_g_i$	$\sum_{i=1}^{N} r\_ne_i$	0

2.5.4. **Protected, Leased cloud Scenario**

- The difference of this case with respect the protected, own cloud scenario is that the protection costs of the cloud should not be considered.

	legacy	SDN	Cloud
Fault Reparation	$\sum_{i=1}^{2N} r\_g_i$	$\sum_{i=1}^{2N} r\_ne_i$	0

OPEN QUESTIONS:

- Time dependence should also be considered
- The dimension of the network and the controllers should be considered
- We can define a percentage α of nodes which are SDN-enabled. Hence, from the total number of nodes, $N.\alpha$ are SDN enabled and $N.(1-\alpha)$ are cloud-based.
- New case study: What does it happen at each scenario when there is a significant increase of users and your network is saturated?
- Should other costs be considered? E.g.
    - Planning has been modelled as 7% of CapEx [SPARC project]
    - Floor space