Architecture and Open Queue Model

Thesis

21 September 2020

1 Introduction

This section will deal with the assumptions we've made so far and why we've made them. Alternatives will be described for the various possibilities.

1.1 Assumptions

1. **Assumption 1**: All layers have no horizontal connection. The scheme we will present in section 2 will feature LANs accessible by all nodes of the same layer so this type of communication is actually possible through those LANs, but for now decided to not have horizontality in the message system.

2. **Assumption 2**: The only entity needing a disk is the Central Node, in particular we are assuming that all other nodes receive information that can be processed, stored and aggregated in the RAM which will never be full. This is a strong assumption that can be relaxed if needed by adding disks in the regional and primary/secondary layer.

3. **Assumption 3**: The RAM element of the nodes doesn't need its own queue model, indeed it can be modeled in symbiosis with the CPU since it is used by only that component.

4. **Assumption 4**: In this first stage we won't be holding account of the fault tolerance of the system, in particular we are not considering duplication of the data not in storaging neither in multiple link sending.

5. **Assumption 5**: Equiprobability of receiving a message on any given level, indeed we will assume that, each time a central sends a message to a node on a level the probability that any one of them is the target is the same, this can be relaxed easily by putting a fixed probability parameter in the formulas.

1.2 Table

First of all, we started by compiling the table with the responses as we expect them to be. The green ones are those decisions we made while the black ones are trivial ones that have no alternatives.

Entity	Generates a transition / telemetry message?	Receives a reply to a transition message?	Generates a command in response to a transition message?	Generates a command independently from a transition message?	Transition messages are sent to nodes in the upper layer?	Telemetry messages are sent to nodes in the upper layer?	Transition messages are sent to nodes in the same layer?	Telemetry messages are sent to nodes in the same layer?	Aggregation rate by message type	There are multiple links to the upper layer?	There is duplication of the messages on different upper links?
Sensor	transition and telemetry	no	no	no	yes	yes	no	no	no	*	no
Actuator	transition only	no	no	no	yes	yes	no	no	no	*	no
Primary Network Node	no	yes	yes	no	yes	yes	no	no	param	*	no
Secondary Network Node	no	yes	no	no	yes	yes	no	no	param	*	no
Regional Node	no	yes	no	no	yes	yes	no	no	param	*	no
Central Node	no	no	no	y	no	no	no	no	param	*	no

Now, row by row we will justify or explain our answers:

1. Generate a transition or telemetry message: the sensor give telemetry informations to the upper node with a certain rate. Both actuators and sensor will generete a transitions message in the case that their state is changed without a transition command received. All others entities have no case in which they need to do so.

2. Receives a reply to a transition message: sensor and actuators don't need an acknowledgment from the upper level, while all other entities do. The only exception is the Central node since he doesn't have an upper node to send to.

3. Generates a command in response to a transition message: the primary reading the transition messages may need to issue commands to actuators in order to keep the system flowing.

4. Generates a command independently from a transition message: none of the entities may generate a command without any trigger, the only exception being the central node which sends commands when needed.

5. Transition messages are sent to nodes in the upper layer: all entities need to send to an upper level until the central node is reached.

6. Telemetry messages are sent to nodes in the upper layer: same as last one.

7. Transition messages are sent to nodes in the same layer: no, for assumption 1.

8. Telemetry messages are sent to nodes in the same layer: no, for assumption 1.

9. Aggregation rate by message type: we don't have the actual rate so we put a parameter in the aggregation formulas.

10. There are multiple links to the upper layer: not useful at the moment for modeling and queue formulas so we skipped over it. Also for Assumption 4 we may implement it in a later stage.

11. There is duplication of the messages on different upper links: No, for assumption 4.

2   Structural scheme

This section will explain how the structural scheme for the system is made and its project's choices.

In the model we are going to show, we used as connection between the upper level node and the LAN of the lower level nodes a WAN between two routers. An alternative is possible if we transform this WAN into a long distance LAN where only one router is needed for this connection on the upper level node side.

The choice of a WAN was made due to the high regional spam that the second level nodes are going to cover.

CENTRAL LEVEL

CENTRAL LAN

R

WAN CENTRAL

R

LAN REGIONAL

REGIONAL LEVEL
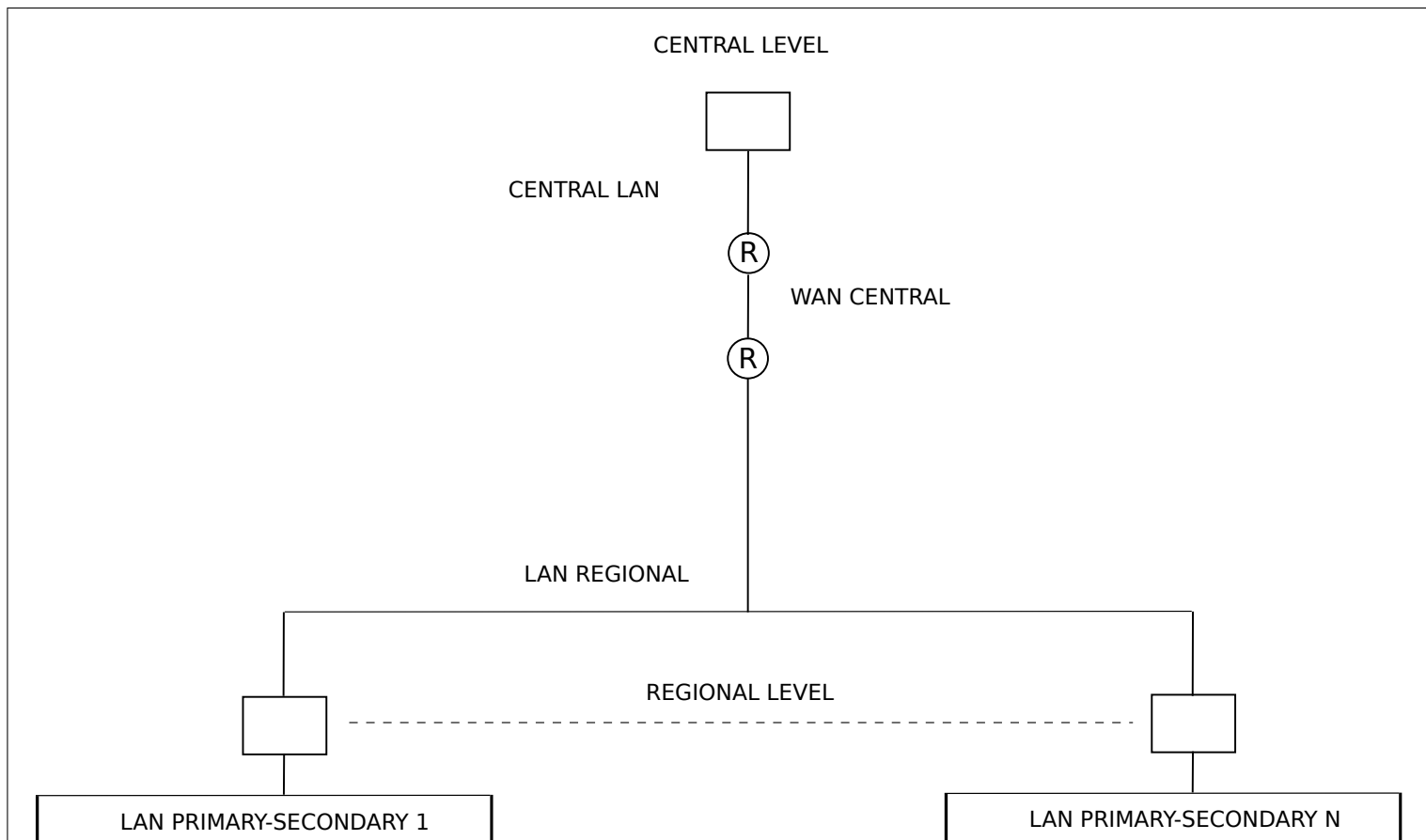
LAN PRIMARY-SECONDARY 1

LAN PRIMARY-SECONDARY N

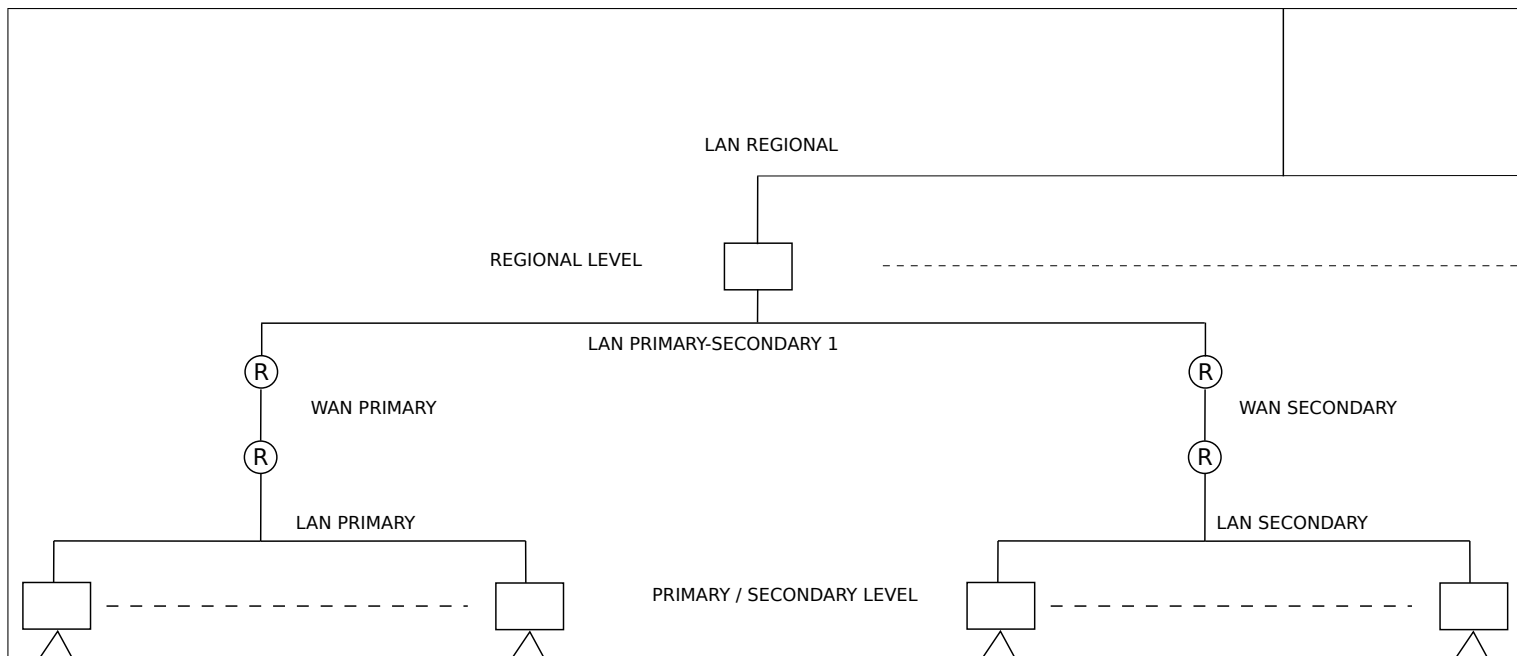Figure 1: Focus on Central and Regional nodes

Figure 2: Focus on Regional and Primary/Secondary nodes

Figure 1 represents the connection between Central and Regional nodes, while Figure 2 shows the connection between Regional and Primary/Secondary. We can see that lower level router is used as an interface for lower level nodes to receive and send messages to the upper level node. Keeping in mind assumption 1 on the horizontal level communication, even if the nodes on a level share a LAN they won't send messages to their peers.
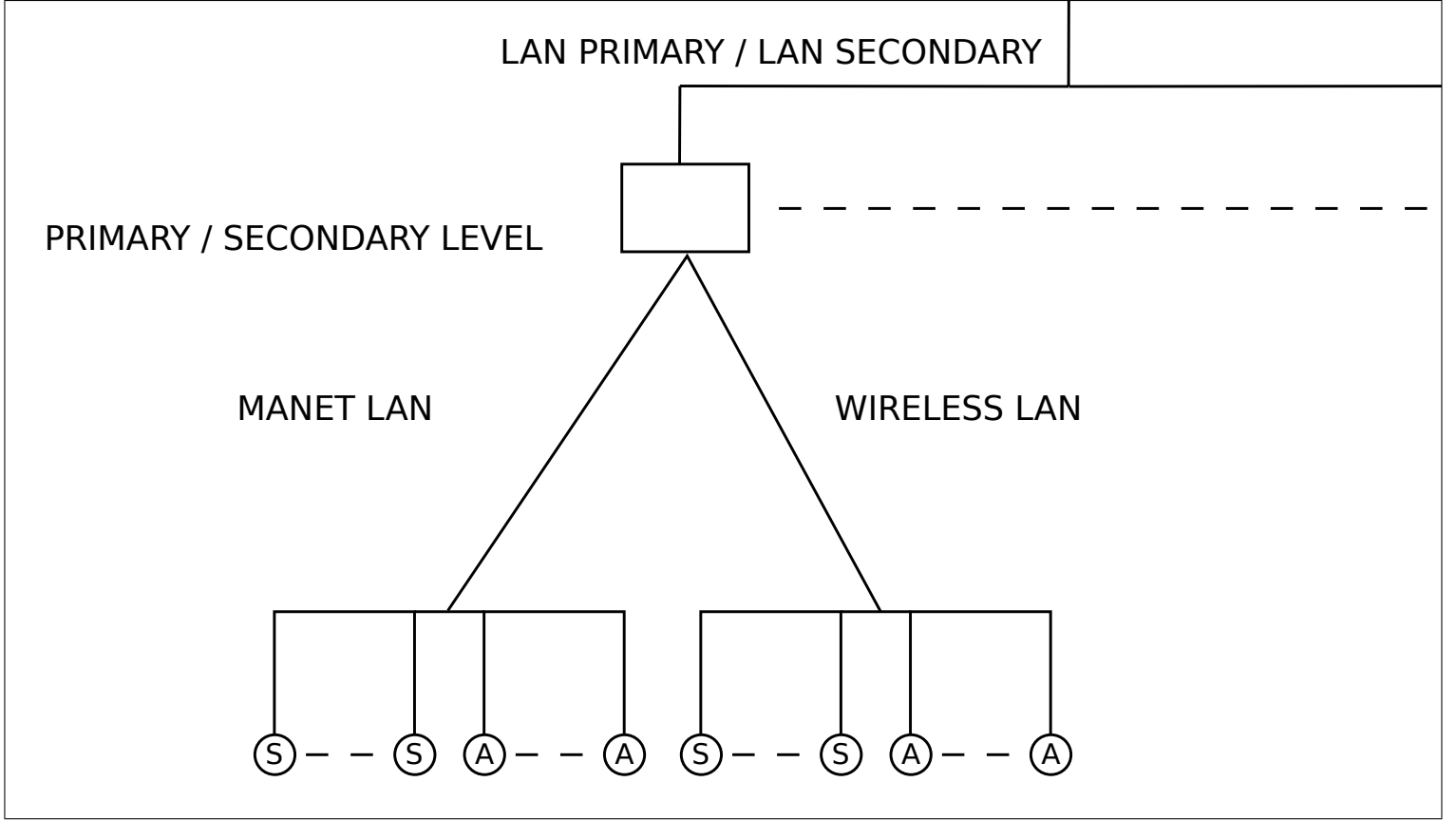
Figure 3: Focus on Primary/Secondary nodes and end points

Instead in figure 3, which displays the connection between Primary/Secondary nodes and the end points of the edge system, namely actuators and sensors, one LAN is used for each type of connection technology, in this case MANET and WIRELESS, both spanning between end points and their respective upper level node node.

Furthermore this iteration is parametric so a central node manages n regional nodes. Each regional node manages m primary and k secondary nodes, these parameters varies with the regional node they are associated to. Same thing extends to primary/secondary with respect to the sensors/actuators, respectively in numbers s and a.

One last note about the scheme is that at the moment we divided on two LANs primary and secondary for clarity since they have different rate, operations and technology. Likewise for the different communication technology with actuators and sensors.
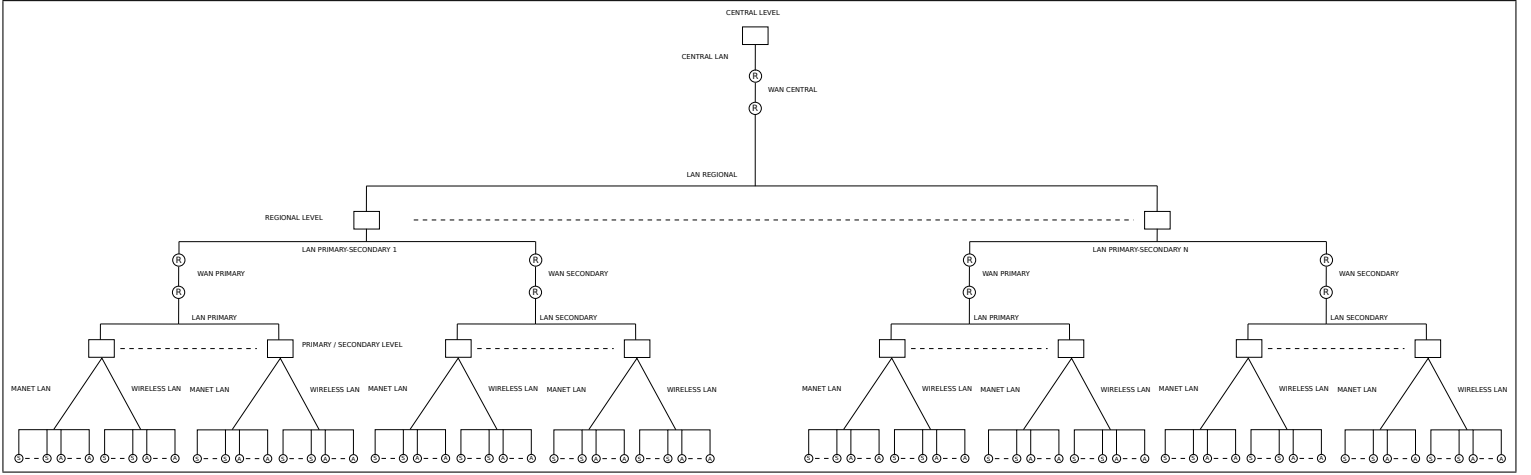
The whole scheme:

Figure 4: Structural scheme

3 Queues Scheme and Formulas

3.1 Classes

-open multiclass quindi formule triviali -Multiclass, which classes, why - Keywords, messages,reply, command

3.2 Notation

We will deline the notation in the following formulas, each of them has one or many subscripts for the item they refer to, the same type of element in a different part has the same notation even though it's not the same element:

- λ_t and λ_e: λ is the arrival rate, respectively for the data type telemetry and transition.

- V: mean number of visits.

- S: service time.

- D: service demand.

- U: utilization factor.

- R: response time.

- cn : central node.

- rn : regional node.

- pn : primary node.

- sn secondary node.

- wl : wireless.

- mt : manet.

- pl : primary lan.

Each node has a summary section which describes the total response time for that node type.
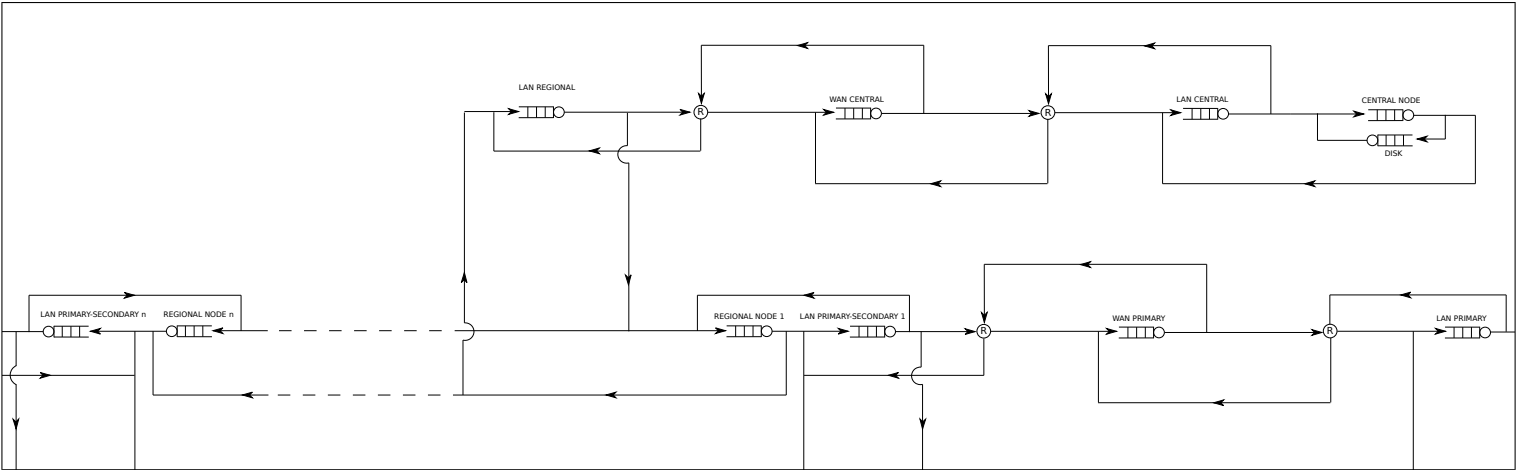To develop the following formulas, we started from the network queue in the case of an open network.

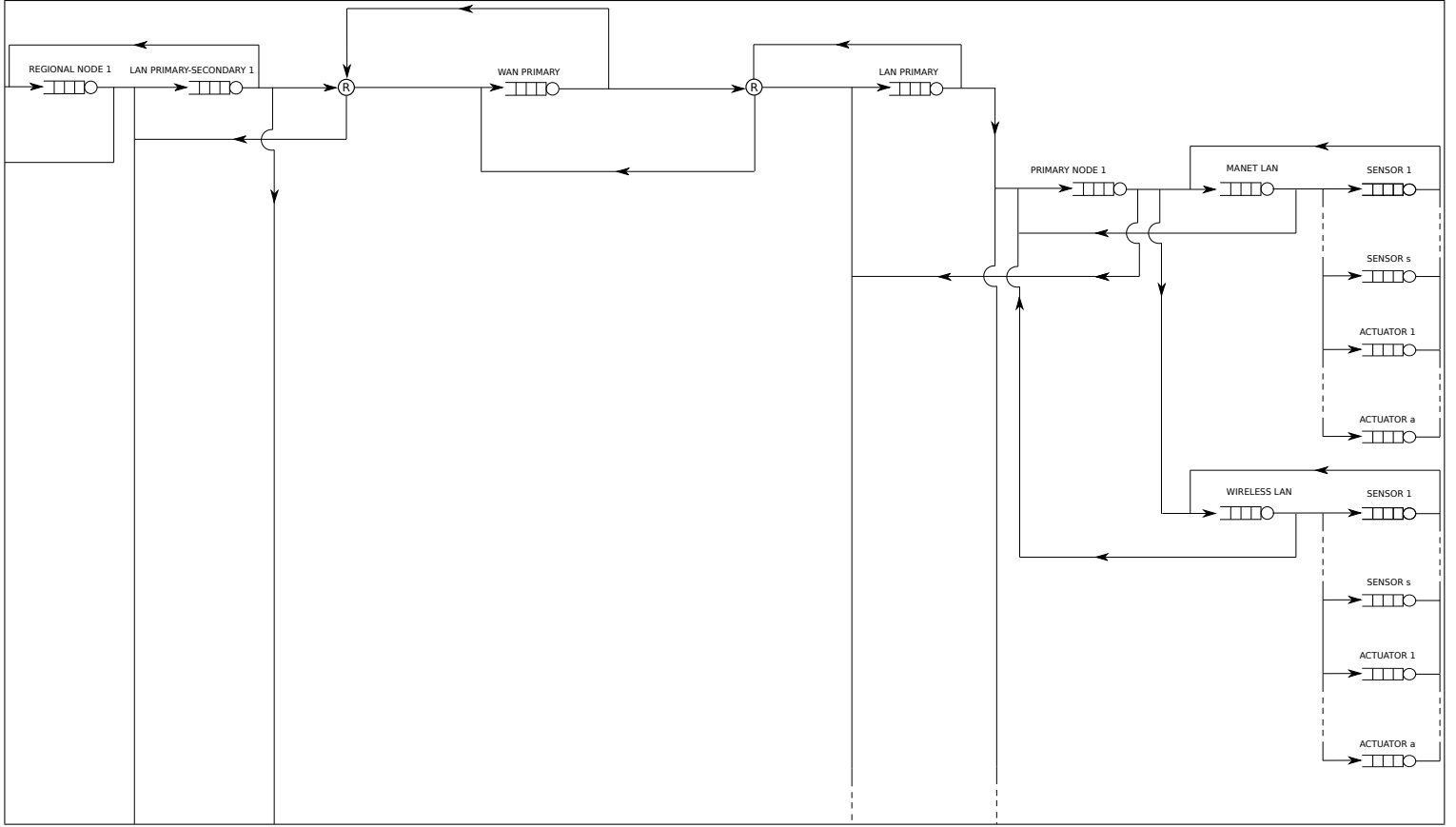Figure 5: Focus on Central and Regional nodes

Figure 6: Focus on Regional nodes, Primary/Secondary nodes and sensor/actuators
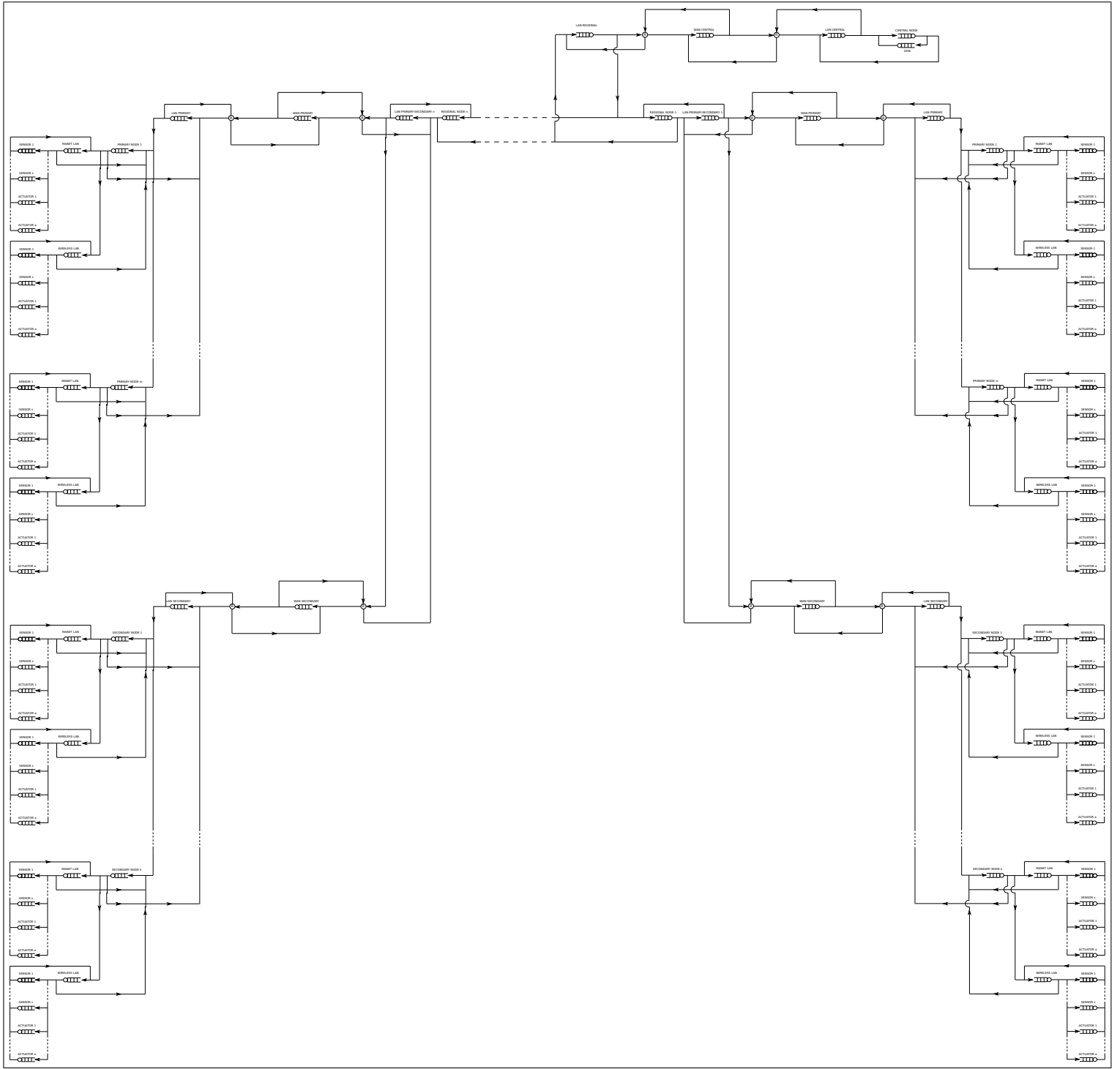
Figure 7: The whole scheme

3.3   Actuators and Sensors

Sensors at the moment don't receive any command, we still have drawn them as queues for future extensions.

3.4   WIRELESS/MANET Lan

e:transition, t: telemtery, c:command -n,m,k,s,a già usati

The first element we are going to look at is the WIRELESS lan. At this stage we are not considering the implication of the different technology thus we will only show the formulas for Wireless and the Manet's formulas will be mirrored.

For the formulas we used the assumption 5 on equiprobability and the table presented in section 1.2, in particular the first four columns.

The mean number of visits is trivially one for telemetry and commands since only one messages goes through the LAN, it's two for transition since a reply is needed.

More interesting are the formulas regarding the arrival rates.

In the telemetry cases the total arrival rate $\lambda_{wl,t}$ is the rate of a single sensor multiplied by the number of sensors.

For transition instead, $\lambda_{wl,e}$ will be a sum of two terms, since both actuators and sensors send messages.

Finally for $\lambda_{wl,c}$, the first term is the case where the central node issues a command, so the sent command of that class of messages will arrive to an actuator with a certain probability, given the assumption 5 this probability is one over the sum of all possible paths that can be taken by this message: one of the regional node, then one of the primary or secondary node and then the MANET or WIRELESS LAN. The second term instead is the case where a command is prompted due to a transition message so we multiply the arrival rate of transition event for primary or secondary node by a probability of the transition to generate a command, divided by two because the two paths, WIRELESS or MANET.

$$
\begin{aligned}
V_{wl,t} &= 1 \\
V_{wl,e} &= 2 \\
V_{wl,c} &= 1 \\
\lambda_{wl,t} &= s * \lambda_{s,t} \\
\lambda_{wl,e} &= s * \lambda_{s,e} + a * \lambda_{a,e} \\
\lambda_{wl,c} &= \frac{\lambda_{cn,c}}{n*(m+k)*2} + prb * \frac{\lambda_{pn,e}}{2}
\end{aligned}
\tag{1}
$$

In the last equation, the second term requires a change from primary node arrival rate to secondary node arrival rate in the case that the upper node is indeed a secondary.

From the previous formulas and the open queue model we can compute the Service Demand, Utilization factor and Response time.

$$
\begin{aligned}
D_{wl,t} &= V_{wl,t} * S_{wl,t} \\
D_{wl,e} &= V_{wl,e} * S_{wl,e} \\
D_{wl,c} &= V_{wl,c} * S_{wl,c} \\
U_{wl,t} &= \lambda_{wl,t} * D_{wl,t} \\
U_{wl,e} &= \lambda_{wl,e} * D_{wl,e} \\
U_{wl,c} &= \lambda_{wl,c} * D_{wl,c} \\
U_{wl} &= U_{wl,t} + U_{wl,e} + U_{wl,c} \\
R_{wl,t} &= \frac{D_{wl,t}}{1-U_{wl}} \\
R_{wl,e} &= \frac{D_{wl,e}}{1-U_{wl}} \\
R_{wl,c} &= \frac{D_{wl,c}}{1-U_{wl}}
\end{aligned}
\tag{2}
$$

3.5 Primary Node

All formulas in this chapter are relatable to the previous one and thus we won't need any note on them.

Formulas for secondary nodes are the same as primary ones for now so we will only discuss these one.

The equations of the previous element will be used as arrival rates for the

primary node thus both MANET and WIRELESS will be referred to.

$$
\begin{aligned}
V_{pn,t} &= 1 \\
V_{pn,e} &= 2 \\
V_{pn,c} &= 1 \\
\lambda_{pn,t} &= \lambda_{wl,t} + \lambda_{mt,t} \\
\lambda_{pn,e} &= \lambda_{wl,e} + \lambda_{mt,e} \\
\lambda_{pn,c} &= \frac{\lambda_{cn,c}}{n*(m+k)} + prb * \lambda_{pn,e}
\end{aligned}
\tag{3}
$$

From the previous formulas and the open queue model we can compute the Service Demand, Utilization factor and Response time.

$$
\begin{aligned}
D_{pn,t} &= V_{pn,t} * S_{pn,t} \\
D_{pn,e} &= V_{pn,e} * S_{pn,e} \\
D_{pn,c} &= V_{pn,c} * S_{pn,c} \\
U_{pn,t} &= \lambda_{pn,t} * D_{pn,t} \\
U_{pn,e} &= \lambda_{pn,e} * D_{pn,e} \\
U_{pn,c} &= \lambda_{pn,c} * D_{pn,c} \\
U_{pn} &= U_{pn,t} + U_{pn,e} + U_{pn,c} \\
R_{pn,t} &= \frac{D_{pn,t}}{1-U_{pn}} \\
R_{pn,e} &= \frac{D_{pn,e}}{1-U_{pn}} \\
R_{pn,c} &= \frac{D_{pn,c}}{1-U_{pn}}
\end{aligned}
\tag{4}
$$

3.6   Primary LAN

-riceve m volte rate primary node diviso aggregazione -aggregation param aggr_pn -parla della m* roba -rispiega la probabilità-qui mettiamo anche la

WAN

$$V_{pl,t} = 1$$
$$V_{pl,e} = 2$$
$$V_{pl,c} = 1$$
$$\lambda_{pl,t} = m * \frac{\lambda_{pn,t}}{aggr_{pn}}$$
$$\lambda_{pl,e} = m * \lambda_{pn,e}$$
$$\lambda_{pl,c} = m * \frac{\lambda_{cn,c}}{n*(m+k)}$$

(5)

From the previous formulas and the open queue model we can compute the Service Demand, Utilization factor and Response time.

$$D_{pl,t} = V_{pl,t} * S_{pl,t}$$
$$D_{pl,e} = V_{pl,e} * S_{pl,e}$$
$$D_{pl,c} = V_{pl,c} * S_{pl,c}$$
$$U_{pl,t} = \lambda_{pl,t} * D_{pl,t}$$
$$U_{pl,e} = \lambda_{pl,e} * D_{pl,e}$$
$$U_{pl,c} = \lambda_{pl,c} * D_{pl,c}$$
$$U_{pl} = U_{pl,t} + U_{pl,e} + U_{pl,c}$$
$$R_{pl,t} = \frac{D_{pl,t}}{1-U_{pl}}$$
$$R_{pl,e} = \frac{D_{pl,e}}{1-U_{pl}}$$
$$R_{pl,c} = \frac{D_{pl,c}}{1-U_{pl}}$$

(6)

Regarding the WAN between LAN Primary-Secondary and LAN Primary, since the WAN forwards al the messages received from the

3.7   Lan Primary-Secondary

$$V_{pl,t} = 1$$
$$V_{pl,e} = 2$$
$$V_{pl,c} = 1$$
$$\lambda_{pl,t} = m * \frac{\lambda_{pn,t}}{aggr_{pn}}$$
$$\lambda_{pl,e} = m * \lambda_{pn,e}$$
$$\lambda_{pl,c} = m * \frac{\lambda_{cn,c}}{n*(m+k)}$$

(7)

From the previous formulas and the open queue model we can compute the Service Demand, Utilization factor and Response time.

$$
\begin{aligned}
D_{pl,t} &= V_{pl,t} * S_{pl,t} \\
D_{pl,e} &= V_{pl,e} * S_{pl,e} \\
D_{pl,c} &= V_{pl,c} * S_{pl,c} \\
U_{pl,t} &= \lambda_{pl,t} * D_{pl,t} \\
U_{pl,e} &= \lambda_{pl,e} * D_{pl,e} \\
U_{pl,c} &= \lambda_{pl,c} * D_{pl,c} \\
U_{pl} &= U_{pl,t} + U_{pl,e} + U_{pl,c} \\
R_{pl,t} &= \frac{D_{pl,t}}{1-U_{pl}} \\
R_{pl,e} &= \frac{D_{pl,e}}{1-U_{pl}} \\
R_{pl,c} &= \frac{D_{pl,c}}{1-U_{pl}}
\end{aligned}
\tag{8}
$$

3.8   Regional Node

3.9   Regional LAN

-qui mettiamo anche la WAN

3.10   Central Node

-qua mettiamo anche disk

3.11   Central LAN

-qui mettiamo anche la WAN

4   Node

4.1   Wifi card

In the equations of the wifi card, the element is called w. So $V_{w,t}$ is the mean number of visits for the wifi card in the case of a telemetry data type. For the wifi card, since there are 4 sensors, the arrival rate for the telemetry

data type is four times the total arrival rate, while due to the single actuator, in the case of a transition event the arrival rate is exactly the same.

$$
\begin{aligned}
V_{w,t} &= 1 \\
V_{w,e} &= 1 \\
\lambda_{w,t} &= 4 * \lambda_t \\
\lambda_{w,e} &= \lambda_e
\end{aligned}
\tag{9}
$$

$$
\begin{aligned}
D_{w,t} &= V_{w,t} * S_{w,t} \\
D_{w,e} &= V_{w,e} * S_{w,e} \\
U_{w,t} &= \lambda_{w,t} * D_{w,t} \\
U_{w,e} &= \lambda_{w,e} * D_{w,e} \\
U_w &= U_{w,t} + U_{w,e} \\
R_{w,t} &= \frac{D_{w,t}}{1-U_w} \\
R_{w,e} &= \frac{D_{w,e}}{1-U_w}
\end{aligned}
\tag{10}
$$

4.2   Ram

The mean number of visits for the transition events is two because after receiving it you need to reply and thus the visits double.

$$
\begin{aligned}
V_{r,t} &= 1 \\
V_{r,e} &= 2 \\
\lambda_{r,t} &= \lambda_{w,t} \\
\lambda_{r,e} &= \lambda_{w,e}
\end{aligned}
\tag{11}
$$

$$
\begin{aligned}
D_{r,t} &= V_{r,t} * S_{r,t} \\
D_{r,e} &= V_{r,e} * S_{r,e} \\
U_{r,t} &= \lambda_{r,t} * D_{r,t} \\
U_{r,e} &= \lambda_{r,e} * D_{r,e} \\
U_r &= U_{r,t} + U_{r,e} \\
R_{r,t} &= \frac{D_{r,t}}{1-U_r} \\
R_{r,e} &= \frac{D_{r,e}}{1-U_r}
\end{aligned}
\tag{12}
$$

4.3 Lan

As in the ram, since there is a reply needed for the transition type the mean number of visits doubles. Every two received messages of the telemetry type, we aggregate them in a single message and send them to the upper level, thus the halving of the arrival rate.

$$
\begin{aligned}
V_{l,t} &= 1 \\
V_{l,e} &= 2 \\
\lambda_{l,t} &= \frac{\lambda_{w,t}}{2} \\
\lambda_{l,e} &= \lambda_{w,e}
\end{aligned}
\tag{13}
$$

$$
\begin{aligned}
D_{l,t} &= V_{l,t} * S_{l,t} \\
D_{l,e} &= V_{l,e} * S_{l,e} \\
U_{l,t} &= \lambda_{l,t} * D_{l,t} \\
U_{l,e} &= \lambda_{l,e} * D_{l,e} \\
U_l &= U_{l,t} + U_{l,e} \\
R_{l,t} &= \frac{D_{l,t}}{1-U_l} \\
R_{l,e} &= \frac{D_{l,e}}{1-U_l}
\end{aligned}
\tag{14}
$$

4.4 Cpu

We will now make a note that will be useful for following formulas as well, focusing on the service demand in both data type cases.

- $\frac{1}{2}S_{c,t,mem} + \frac{1}{2}S_{c,t,aggr}$: in the cpu service demand for the telemetry case, we put the sum of half the service time in memorization and aggregation because the aggregation rate is $\frac{1}{2}$. Indeed, each time a telemetry event arrives can trigger one of the two actions with the same probability.

- $\frac{1}{2}S_{c,e,new} + \frac{1}{2}S_{c,e,repl}$: specularly in the case of a transition event, the two cases are when the cpu receives a new message or it receives an acknowledgment of a message it already sent.

19

$$V_{c,t} = 1$$
$$V_{c,e} = 2$$
$$\lambda_{c,t} = \lambda_{w,t}$$
$$\lambda_{c,e} = \lambda_{w,t}$$
(15)

$$D_{c,t} = V_{c,t} * (\tfrac{1}{2}S_{c,t,mem} + \tfrac{1}{2}S_{c,t,aggr})$$
$$D_{c,e} = V_{c,e} * (\tfrac{1}{2}S_{c,e,new} + \tfrac{1}{2}S_{c,e,repl})$$
$$U_{c,t} = \lambda_{c,t} * D_{c,t}$$
$$U_{c,e} = \lambda_{c,e} * D_{c,e}$$
$$U_c = U_{c,t} + U_{c,e}$$
$$R_{c,t} = \tfrac{D_{c,t}}{1-U_c}$$
$$R_{c,e} = \tfrac{D_{c,e}}{1-U_c}$$
(16)

4.5 Summary

$$R_{node,\ t} = R_{w,t} + R_{r,t} + R_{c,t} + R_{l,t}$$
$$R_{node,\ e} = R_{w,e} + R_{r,e} + R_{c,e} + R_{l,e}$$
(17)

5 Regional Node

5.1 Lan down

The arrival rate for transition type formula is given by the fact that there are two clients but there is aggregation so we have $\frac{\lambda_{w,t}}{2}$ for each client.

$$V_{ld,t} = 1$$
$$V_{ld,e} = 2$$
$$\lambda_{ld,t} = 2 * \frac{\lambda_{w,t}}{2}$$
$$\lambda_{ld,e} = 2 * \lambda_{w,e}$$
(18)

$$D_{ld,t} = V_{ld,t} * S_{ld,t}$$
$$D_{ld,e} = V_{ld,e} * S_{ld,e}$$
$$U_{ld,t} = \lambda_{ld,t} * D_{ld,t}$$
$$U_{ld,e} = \lambda_{ld,e} * D_{ld,e} \tag{19}$$
$$U_{ld} = U_{ld,t} + U_{ld,e}$$
$$R_{ld,t} = \frac{D_{ld,t}}{1 - U_{ld}}$$
$$R_{ld,e} = \frac{D_{ld,e}}{1 - U_{ld}}$$

5.2 Ram

$$V_{r,t} = 1$$
$$V_{r,e} = 2$$
$$\lambda_{r,t} = \lambda_{ld,t} \tag{20}$$
$$\lambda_{r,e} = \lambda_{ld,e}$$

$$D_{r,t} = V_{r,t} * S_{r,t}$$
$$D_{r,e} = V_{r,e} * S_{r,e}$$
$$U_{r,t} = \lambda_{r,t} * D_{r,t}$$
$$U_{r,e} = \lambda_{r,e} * D_{r,e} \tag{21}$$
$$U_r = U_{r,t} + U_{r,e}$$
$$R_{r,t} = \frac{D_{r,t}}{1 - U_r}$$
$$R_{r,e} = \frac{D_{r,e}}{1 - U_r}$$

5.3 Lan Up

$$V_{lu,t} = 1$$
$$V_{lu,e} = 2$$
$$\lambda_{lu,t} = \frac{\lambda_{ld,t}}{2} \tag{22}$$
$$\lambda_{lu,e} = \lambda_{ld,e}$$

$$D_{lu,t} = V_{lu,t} * S_{lu,t}$$
$$D_{lu,e} = V_{lu,e} * S_{lu,e}$$
$$U_{lu,t} = \lambda_{lu,t} * D_{lu,t}$$
$$U_{lu,e} = \lambda_{lu,e} * D_{lu,e} \tag{23}$$
$$U_{lu} = U_{lu,t} + U_{lu,e}$$
$$R_{lu,t} = \frac{D_{lu,t}}{1-U_{lu}}$$
$$R_{lu,e} = \frac{D_{lu,e}}{1-U_{lu}}$$

5.4 Cpu

$$V_{c,t} = 1$$
$$V_{c,e} = 2$$
$$\lambda_{c,t} = \lambda_{ld,t} \tag{24}$$
$$\lambda_{c,e} = \lambda_{ld,e}$$

$$D_{c,t} = V_{c,t} * \left(\tfrac{1}{2} S_{c,t,mem} + \tfrac{1}{2} S_{c,t,aggr} \right)$$
$$D_{c,e} = V_{c,e} * \left(\tfrac{1}{2} S_{c,e,new} + \tfrac{1}{2} S_{c,e,repl} \right)$$
$$U_{c,t} = \lambda_{c,t} * D_{c,t}$$
$$U_{c,e} = \lambda_{c,e} * D_{c,e} \tag{25}$$
$$U_c = U_{c,t} + U_{c,e}$$
$$R_{c,t} = \frac{D_{c,t}}{1-U_c}$$
$$R_{c,e} = \frac{D_{c,e}}{1-U_c}$$

5.5 Summary

$$R_{regional,\ t} = R_{ld,t} + R_{r,t} + R_{c,t} + R_{lu,t}$$
$$R_{regional,\ e} = R_{ld,e} + R_{r,e} + R_{c,e} + R_{lu,e} \tag{26}$$

6 Central

6.1 Lan

$$
\begin{aligned}
V_{l,t} &= 1 \\
V_{l,e} &= 2 \\
\lambda_{l,t} &= 2 * \frac{\lambda_{ld,t}}{2} \\
\lambda_{l,e} &= 2 * \lambda_{ld,e}
\end{aligned}
\tag{27}
$$

$$
\begin{aligned}
D_{l,t} &= V_{l,t} * S_{l,t} \\
D_{l,e} &= V_{l,e} * S_{l,e} \\
U_{l,t} &= \lambda_{l,t} * D_{l,t} \\
U_{l,e} &= \lambda_{l,e} * D_{l,e} \\
U_l &= U_{l,t} + U_{l,e} \\
R_{l,t} &= \frac{D_{l,t}}{1-U_l} \\
R_{l,e} &= \frac{D_{l,e}}{1-U_l}
\end{aligned}
\tag{28}
$$

6.2 Ram

$$
\begin{aligned}
V_{r,t} &= 1 \\
V_{r,e} &= 2 \\
\lambda_{r,t} &= \lambda_{l,t} \\
\lambda_{r,e} &= \lambda_{l,e}
\end{aligned}
\tag{29}
$$

$$
\begin{aligned}
D_{r,t} &= V_{r,t} * S_{r,t} \\
D_{r,e} &= V_{r,e} * S_{r,e} \\
U_{r,t} &= \lambda_{r,t} * D_{r,t} \\
U_{r,e} &= \lambda_{r,e} * D_{r,e} \\
U_r &= U_{r,t} + U_{r,e} \\
R_{r,t} &= \frac{D_{r,t}}{1-U_r} \\
R_{r,e} &= \frac{D_{r,e}}{1-U_r}
\end{aligned}
\tag{30}
$$

6.3 Cpu

$$\begin{aligned}
V_{c,t} &= 1 \\
V_{c,e} &= 2 \\
\lambda_{c,t} &= \lambda_{l,t} \\
\lambda_{c,e} &= \lambda_{l,e}
\end{aligned} \tag{31}$$

$$\begin{aligned}
D_{c,t} &= V_{c,t} * \left(\tfrac{1}{2}S_{c,t,mem} + \tfrac{1}{2}S_{c,t,aggr}\right) \\
D_{c,e} &= V_{c,e} * \left(\tfrac{1}{2}S_{c,e,new} + \tfrac{1}{2}S_{c,e,repl}\right) \\
U_{c,t} &= \lambda_{c,t} * D_{c,t} \\
U_{c,e} &= \lambda_{c,e} * D_{c,e} \\
U_c &= U_{c,t} + U_{c,e} \\
R_{c,t} &= \frac{D_{c,t}}{1 - U_c} \\
R_{c,e} &= \frac{D_{c,e}}{1 - U_c}
\end{aligned} \tag{32}$$

6.4 Disk

The arrival rate of the telemetry events on disks is halved because after the last aggregation, the data is saved on the disk.

$$\begin{aligned}
V_{d,t} &= 1 \\
V_{d,e} &= 1 \\
\lambda_{d,t} &= \frac{\lambda_{l,t}}{2} \\
\lambda_{d,e} &= \lambda_{l,e}
\end{aligned} \tag{33}$$

$$\begin{aligned}
D_{d,t} &= V_{d,t} * S_{d,t} \\
D_{d,e} &= V_{d,e} * S_{d,e} \\
U_{d,t} &= \lambda_{d,t} * D_{d,t} \\
U_{d,e} &= \lambda_{d,e} * D_{d,e} \\
U_d &= U_{d,t} + U_{d,e} \\
R_{d,t} &= \frac{D_{d,t}}{1 - U_d} \\
R_{d,e} &= \frac{D_{d,e}}{1 - U_d}
\end{aligned} \tag{34}$$

6.5 Summary

$$R_{central, \ t} = R_{l,t} + R_{r,t} + R_{c,t} + R_{d,t}$$
$$R_{central, \ e} = R_{l,e} + R_{r,e} + R_{c,e} + R_{d,e} \tag{35}$$

7 Results

The following equations we impose a constraint on the total response time for the two message types.

$$R_t = R_{node,t} + R_{regional,t} + R_{central,t} < Max_t$$
$$R_e = R_{node,e} + R_{regional,e} + R_{central,e} < Max_e \tag{36}$$