D4.2 – PRIMARY SYSTEM ARCHITECTURE

Project Acronym:	**Smart RRS**
Project Full Title:	**Innovative Concepts for smart road restraint systems to provide greater safety for vulnerable road users.**
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SUMMARY:

This document reviews the requirements for the Smart RRS primary safety system and from these proposes a system implementation based around a gateway module monitoring the output of a number of environmental and stationary obstruction sensing modules. The sensing modules are arranged as a star network with the gateway, all communications taking place through the gateway at the hub of the network.

The key modules for the system are the sensing modules ("environmental" and "stationary obstruction"), the gateway module, a control centre, an emulation of a vehicle-activated variable message display sign, and an approaching vehicle radar sensor.

The sensing modules detect the occurrence of potentially hazardous situations. The gateway forms the communications hub for the system, receiving messages from (and transmitting messages to) the sensing modules and the variable message sign, the latter being the means by which oncoming traffic is warned that a potentially hazardous situation exists.

The sensing modules comprise the sensors themselves (a combination of temperature, relative humidity, and rain sensors in the case of the environmental sensing module, and an optical reflective sensor in the case of the stationary obstruction sensing module); a processing sub-system to run algorithms for interpreting the received sensor data as well as controlling the power and communications sub-systems; a radio sub-system to enable wireless communication using a wireless personal area network (WPAN) protocol with the gateway; and a power sub-system to provide long-term power to the sensing modules.

The gateway module monitors the sensing modules using a wireless personal area network (WPAN) protocol and communicates to a remote control centre using GPRS. In addition to communication functions, the gateway module also provides some logic for controlling the vehicle-activated variable message sign, based on data from the sensing modules combined with detection of approaching vehicles. The gateway module also has the function of providing some time synchronization for the sensing modules.

The control centre receives and stores status data from the sensing modules and provides means for examining this data.

Contents

1. INTRODUCTION

This document gives an overview of the architecture for the Primary Safety System and identifies the requirements on the various sub-systems.

This document is aimed primarily at defining the sub-systems for the demonstration systems. Where these are likely to be significantly different from a production system the document makes this clear.

The document also discusses some of the options for the implementation of these sub-systems.

Top level requirements for the system (from Smart RRS Requirements Document D4.1) are as listed in the following sub-sections.

Some aspects of the operation of the Primary Safety System are the same as those already developed and documented for the Tertiary Safety System. In such cases, where there is overlap of information, reference to the relevant Tertiary System documents is made, rather than repeating information unnecessarily in this document.

1.1 TOP-LEVEL FUNCTIONAL REQUIREMENTS

FR.1. During installation, it shall be possible to register the location of each data source (e.g. sensing node) and to store that location at each data source.

FR.2. The system shall detect or infer some or all of the following parameters (derived from Table 6 in D4.1[1]):

a. Oncoming traffic – for the situation of a single carriageway road where the road restraint system is positioned along a bend and oncoming traffic might be obscured[2].

b. Vehicle speed.

c. Slippery road surface (rain, ice)

d. Object detection[3].

e. Rain, mist, fog (reduced visibility).

Note that it may be that not all of these will be possible within the scope of the demonstration.

Consideration needs to be given as the project progresses to the issues of both false and missed detections which might undermine the credibility of any practical system.

FR.3. The system shall demonstrate how it might communicate to drivers approaching the road section on which the system is installed. It shall communicate appropriate messages relating to each of the sensed parameters listed above.

Note that this aspect of the demonstration will only be a simulated representation of messages away from the roadside – for example displaying

[1] Smart RRS Deliverable D4.1: Concept Requirements for Smart RRS Primary Safety System.

[2] For clarification, the bend (rather than the road restraint system) might cause the obscuration

[3] The size and range of object to be detected will be considered in more detail in later documents.

simulated roadside messages on a remote laptop monitor which is emulating a variable message sign – see Section 3.4.

FR.4. The system shall be capable of demonstrating how it might communicate to an approaching driver in a timely manner.

FR.5. The system shall communicate to a control centre. It shall communicate at least the same messages as are communicated to the driver. Note that this data is for system logging purposes and not for display to control centre operators.

FR.6. The system shall communicate to the control centre the time at which each message or measurement or detection was made and the location of the source of each one. Note that this data is for system logging purposes and not for display to control centre operators.

FR.7. The system shall also communicate to the traffic control centre more detailed messages once per day as shall be necessary for monitoring the performance of the system itself. Note that this data is for system logging purposes and not for display to control centre operators.

FR.8. The traffic control centre shall have means to display and store the data received from the system.

FR.9. The system shall be able to provide simple diagnostic information from each element within the system.

Note that the functionality described in FR5 to FR8 may not be demonstrated in the Primary Safety System demonstration: this functionality will be demonstrated as part of the Tertiary Safety System demonstration where the communication with the Control Centre is a more critical aspect of the operation of the system. In future implementations of the system, it may be possible for the control centre to request additional information from the system (for example, if appropriate to the final implementation, still images from a camera): however, this functionality will not be implemented in the demonstration system.

1.2 TOP-LEVEL OTHER REQUIREMENTS

OR.1. At least the sensing part of the Smart RRS system shall be capable of being mounted on the crash barrier.

OR.2. The mounting of any part of the Smart RRS system on the barrier shall not present an additional hazard to a PTW or other vulnerable road user in collision with the barrier.

OR.3. The mounting of any part of the Smart RRS system on the barrier shall not interfere with the containment or energy absorption functions of the barrier.

OR.4. The system shall make minimal demands on the wired infrastructure for power.

OR.5. The system shall make minimal demands on the wired infrastructure for communications with road users and traffic control centres.

OR.6. All external (outdoors) elements of the system shall meet a rating of at least IP54.

OR.7. All external elements of the system shall be able to withstand an ambient temperature range commensurate with homologation requirements for roadside infrastructure.

OR.8. The system shall comply with EMC standards called for by the homologation requirements for roadside infrastructure.

2. OVERVIEW

The primary safety system will consist of a number of modules as illustrated in Figure 1:

- Two different types of sensing module (environmental sensing module and stationary obstruction sensing module) that detect and evaluate events and parameters and communicate these to the gateway (GW) module.
- A GW module that gathers data from a number of sensing modules and passes it back to the control centre. In future implementations, the GW module may also receive commands or data from the control centre and forward these to the sensing modules, but this functionality won't be demonstrated in the proposed demonstration system.
- A control centre which is the point within the Smart RRS system to which data is ultimately sent. This will also monitor the performance of the other modules and allow simple diagnostics of these to take place.
- A Vehicle Activated Display emulator which will be able to inform oncoming vehicles that a hazardous situation exists through display of appropriate messages.

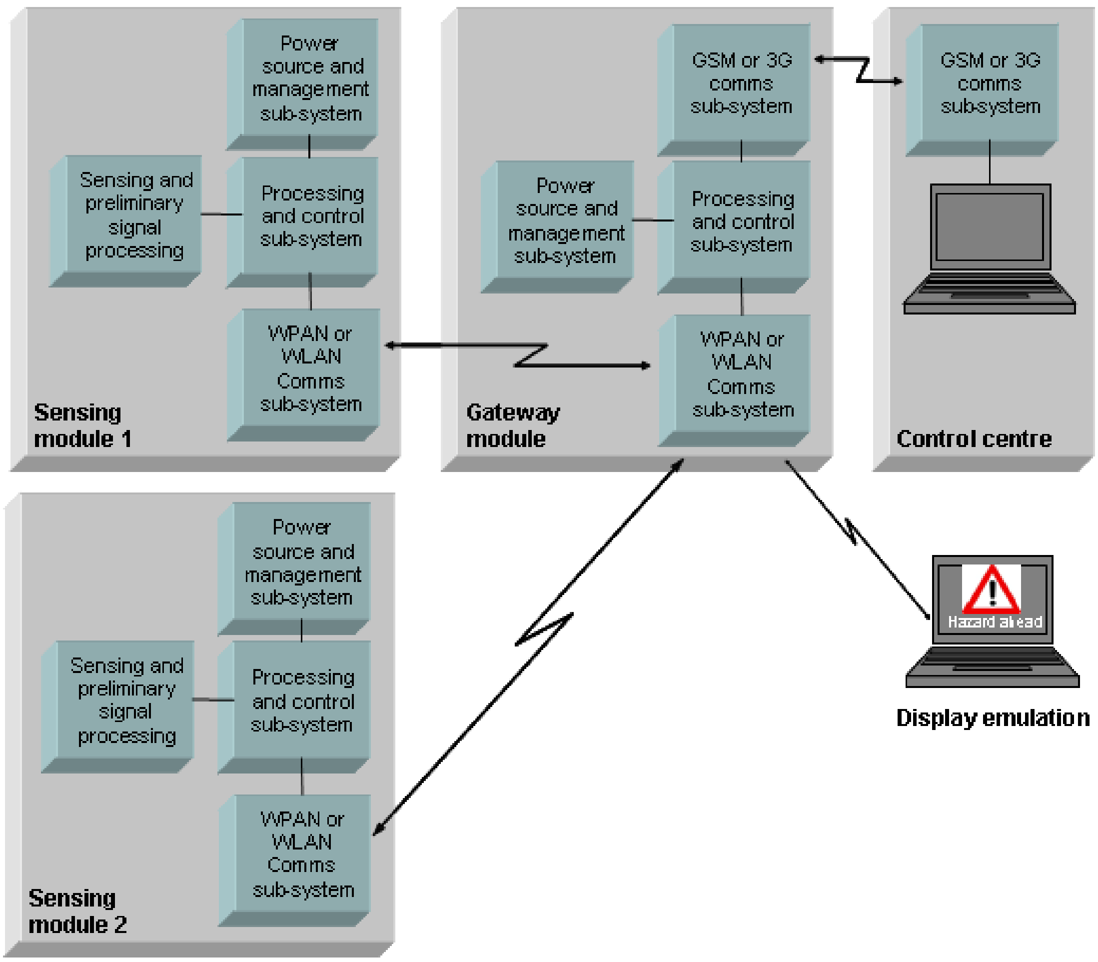

Figure 1: Top Level View of Smart RRS Primary Safety System

The system will use a "star" topology with the GW module as the hub for all communications and the sensing modules communicating only with the gateway (rather than allowing peer to peer communication between the sensing modules). This is in order to keep the system simple for the purposes of demonstration and to minimize the power requirements of the sensing modules.

Communications between the GW module and the sensing modules will be initiated by the sensing modules – i.e. they will communicate either when they have information to transmit or at a fixed time interval for status updates. This relieves the sensing module of the power-burden of an RF receiver continually listening for data requests from the GW module. Information communicated by a sensing module is automatically passed through to the control centre by the GW module.

It has been decided that, for the purposes of demonstration within the scope of the project, the primary safety system shall be configured for application in a rural, "low-tech" road environment where there is little available infrastructure[4]. This therefore drives the system towards low-power operation since the power will need to be provided via batteries backed up with additional power derived from scavenging or harvesting techniques.

The main hazards to be sensed by the system are:

- Stationary obstructions (both vehicles and other "objects" such as people. For the purposes of having a development target, we choose a minimum "size" of object of 1 m and a maximum range of 10 m).
- Dangerous environmental conditions (demonstration system to be limited to detection air temperature and humidity close to the road surface, and occurrence of rain).

It has already been noted (under FR.2) that consideration should be given to the issues of false and missed detection. The measurement accuracy of these systems will be determined as the project progresses.

In the final system, information will be presented to drivers by means of a variable message sign or by means of some form of infrastructure to vehicle communications. These will provide some indication of the nature of the hazard present in the instrumented section of road. For demonstration purposes, this function will be emulated by a lap-top computer (see Section 3.4), and controlled via the GW module.

Note that the requirements identified in the D4.1 requirements document included a requirement to detect oncoming traffic (see FR.2.a por encima de). In the proposed demonstration system, on-coming traffic will be detected using a dedicated off-the-shelf sensor (e.g. Doppler radar): this sensor data will be used to control the display of messages on the variable message sign (that is, information will only be displayed when an on-coming vehicle is detected, in order to help preserve system power). To keep the demonstration manageable, this will not be used to trigger warnings about oncoming vehicles to drivers coming in the opposite direction.

Note too that the FR.2 also mentions fog detection. Although this may be possible with the sensor set being proposed, again for the sake of keeping the demonstration manageable, this will not be explicitly sensed,

[4] *100630 - Positioning Statement for the Sensor Design v0.4.doc*; Internal Briefing Note from Mouchel Ltd.

3. SMART RRS PRIMARY SYSTEM ARCHITECTURE AND OPERATION

The Smart RRS Primary Safety System bears a number of similarities to the Tertiary (crash sensing) Safety System described in Smart RRS documents D5.1 and D5.2: (i) the Primary Safety System maintains a regular “status update” of sensing modules within the Primary Safety System network; (ii) the Primary Safety System detects and responds to irregular (asynchronous) “events”. The main differences between the two safety system concepts are in the type of “events” detected, and the actions taken in response to these events. Whereas the Tertiary Safety System is intended to detect impacts with the crash barrier and to respond by alerting (using GSM / GPRS) the emergency services via a remote control centre, the Primary Safety System is intended to detect hazardous situations existing in the zone of the instrumented crash barrier, and to provide a local warning (via a variable message sign) to drivers of approaching vehicles that a hazard exists.

For this discussion, the Primary Safety System architecture is assumed to be as shown in Figure 2. It should be noted that the Primary Safety System demonstration system will not be identical with the expected real-life system (for example, the demonstration system will use a lap-top computer to emulate the variable message sign, rather than using an actual sign): where differences between the demo system and the real-life system are expected to occur, these are indicated in the discussion below. It is also intended that the demonstrations of the Primary Safety System and the Tertiary Safety System will be separate demonstrations (so that the network in each case will only be configured either for “hazard event” detection (Primary Safety System) or for “crash event” detection (Tertiary Safety System). For a production system, however, both of these functions will be accommodated within the same architecture, so that a single GW module would need to be able to respond appropriately to either (or both) types of event.

The Smart RRS Primary Safety System will comprise a number of sub-systems and modules which operate together to allow hazardous situations to be detected and communicated to the driver of a vehicle approaching the hazardous area via a variable-message sign (VMS). The main Primary Safety System modules are:

(i) environmental sensing module

(ii) stationary obstacle sensing module

(iii) GW module

(iv) control centre

(v) vehicle-activated display emulator

These are discussed in more detail in the following sub-sections.

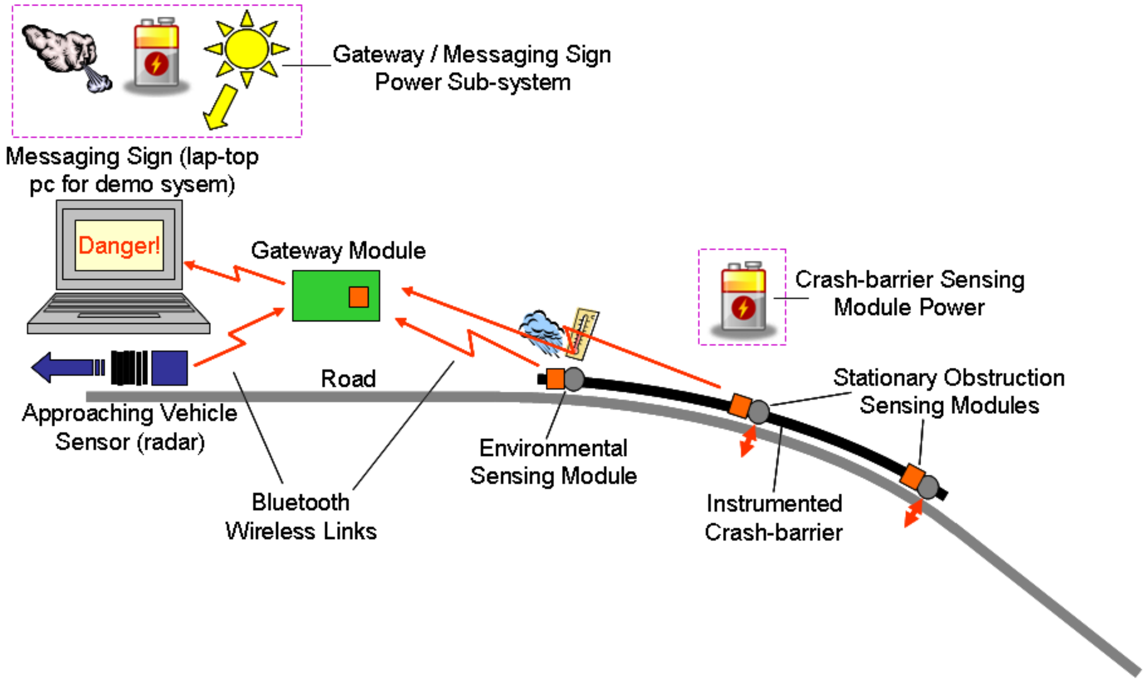

Figure 2 : Proposed Smart RRS Primary Safety System Configuration

3.1 ENVIRONMENTAL SENSING MODULE

This module will comprise a set of battery-powered environmental sensors which monitor a number of environmental parameters and allow determination of when a hazardous environmental condition (e.g. road ice) exists. The module(s) will be mounted on or beside the crash barrier and will communicate with the GW module via wireless data transmission when a hazardous situation is detected. The transmitted message might simply be a single code meaning “hazard”, or it might differentiate between a limited number of different types of hazard (e.g. “fog”, “ice”, “surface water”, etc.) For the Smart RRS demonstration system, only one environmental sensing module will be required. The basic module configuration is shown in

Figure 3.

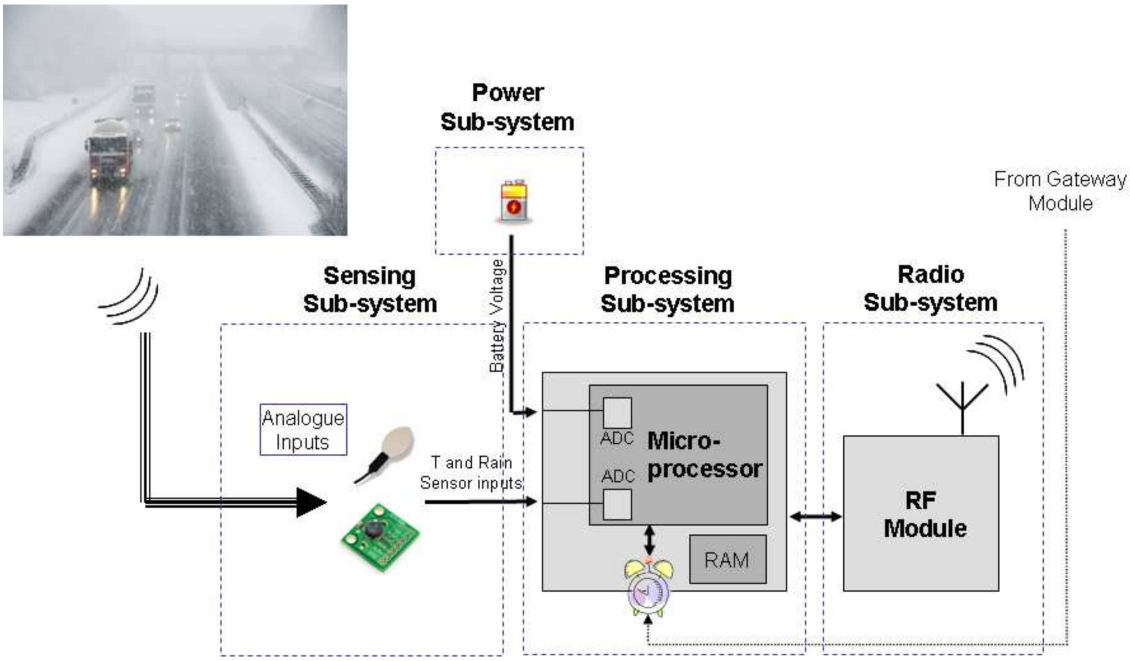

Figure 3 : Environmental Sensing Module Configuration

3.1.1 ENVIRONMENTAL SENSING MODULE REQUIREMENTS

The environmental sensing module requirements listed below are derived from the "top-level" requirements given in Section 1. Some additional "desirable" features are also listed below: whilst not "requirements" as such, these are things which may also help to drive the choice of system components and architecture.

Requirements (must haves) for primary safety system environmental sensing module:

SMR1 – The module shall detect (or infer) that a hazardous road surface condition (wet, icy) is likely to exist, or that such a condition has ceased to exist.

SMR2 – The module shall be able to communicate a message to the GW module indicating that a hazardous road condition is likely to exist, or has ceased to exist.

SMR3 – The module shall be attached to (mounted on) the crash barrier.

SMR4 – The module shall not (in itself) represent an additional hazard.

SMR5 – The module shall not adversely interfere with the safety / energy-absorbing functionality of the crash barrier.

SMR6 – The module shall make minimal demands on the wired infrastructure for power.

SMR7 – The module shall be able to survive roadside environmental conditions.

Desirables (nice-to-haves) for primary safety system environmental sensing module:

SMD1 – The module may be able to determine [more information about] the prevailing environmental conditions (for example, presence of fog)

SMD2 – The module may be developed into a stand-alone product – implies novelty.

SMD3 – The module cost should be minimized.

SMD4 – The module should be powered through energy harvesting techniques if battery life is insufficient

3.1.2 SENSING SUB-SYSTEM

In principle, it is possible to incorporate a comprehensive set of sensors for monitoring or inferring a range of road and environmental condition parameters. Road weather station systems supplied by (e.g.) Campbell Scientific (http://www.campbellsci.co.uk) or specialist road surface condition sensors such as those supplied by Lufft (http://www.barber-insys.co.uk/meteo/meteo1.html) are available: however, these are expensive and not really designed for the type of low-power operation envisaged for the Smart RRS Primary Safety System. Therefore, a more limited system is required in this case.

The idea proposed for the Smart RRS environmental sensor module is to measure just three parameters – temperature, relative humidity, and occurrence of rain – and from a straightforward combination of these measurements to provide an indication of potentially hazardous conditions (for example, the presence of road surface water, ice, etc.) Future development of the system could potentially incorporate a much more comprehensive set of measurements for determining potentially hazardous road surface conditions, but the above is considered appropriate for the demonstration system.

For the purposes of the demonstration system therefore, the following sensors are proposed for the environmental sensing module:

Temperature Sensor:	e.g. Analog Devices AD592 Temperature Transducer or National Semiconductor LM60 Temperature Sensor.
Relative Humidity Sensor:	e.g. Sensirion SHT21 Humidity and Temperature Sensor
Rain sensor:	e.g. Decagon Leaf Wetness Sensor

Wider discussion of sensor options and the reasons behind these sensor choices can be found in Section 6 (Appendix 1).

In terms of system lay-out, the rain sensor will be a stand-alone sensor, bolted to the crash barrier support post, and physically wired to the system enclosure containing the processor and radio sub-systems. The relative humidity sensor (which may also include its own temperature sensor) will be housed within this same enclosure, but the additional system temperature sensor (e.g. AD592) may be housed in a separate enclosure positioned close to the base of the crash barrier support post, and wired to the processor / radio enclosure, in order to provide an indication of air temperature close to the road surface.

3.1.3 PROCESSING SUB-SYSTEM

The processing sub-system for the environmental sensing module will be based on a variant of the **Texas Instruments MSP430** microcontroller. This sub-system will perform the following primary functions:

- control the timing of the excitation and reading of the temperature and rain sensors;
- control the operation of the radio sub-system;
- receive as inputs into its front-end ADCs (or into GPIO pins in the case of digital inputs) the sensor signals and battery voltage level signal;
- process the sensor data to decide if a hazardous situation exists;

- when a hazardous situation (or a low battery voltage) exists, formulate a data packet for transmission via the radio sub-system to the Smart RRS Primary Safety System GW module;
- provide a clock facility to enable system synchronization to be maintained, and to allow control of event timings (e.g. sensor interrogation);
- provide regular “status” updates (once per day) sent as data packets via the radio sub-system to the GW module.

Note that, for this module, sampling of the sensor data is likely to be done on a timed basis (rather than being “event-driven”). The timing schedule is to be determined and may change if (for example) it is recognized that the environmental conditions appear to be approaching a hazardous state.

Note, too, that as far as possible the same processing platform will be used for all the sensing modules within the Smart RRS project (both Primary and Tertiary).

3.1.4 RADIO SUB-SYSTEM

A wide range of wireless protocols and wireless system suppliers has been considered for all the Smart RRS modules. Wireless protocols which have been considered include:

- ZigBee (many vendors; many module options)
- Bluetooth (as ZigBee)
- DASH7 (433 MHz low bandwidth protocol with extended range; limited number of vendors
- WiFi (802.11 standard – long range but more power-hungry; many vendors and module options)
- Proprietary 802.15.4-based protocols (many variants available from many vendors)

The optimum choice of wireless protocol will depend on several factors, including:

- Range over which data must be transmitted (sensing sub-system modules to GW modules);
- Amount and frequency of data transmission;
- Power requirements (transmission power and power management functionality);
- Cost and availability of components;
- System topology and operating mode;
- Degree of vendor support / level of familiarity and expertise already present within Smart RRS consortium;

However, in addition to the above requirements, the wireless protocol choice will also depend on the need to communicate reliably with the GW module which is intended to be an off-the-shelf product: hence, the choice will in reality be limited to those wireless protocols which are compatible with the available GW modules. The main driving factor behind the choice of wireless protocol and radio module is therefore the availability of a suitable off-the-shelf GW module which allows GSM / GPRS functionality as well as the standard wireless functionality for LAN-based data gathering and transmission. Relatively few such GW modules are currently available which are suitable for use in the Smart RRS Primary (and Tertiary) Safety Systems.

The selected GW module is the Access Point Gateway (APG) module supplied by Laird Technologies (see Section 8 – Appendix 3 – **¡Error! No se encuentra el origen de la referencia.**for detailed discussion) , and the intention is that the radio sub-system will be based on the **Ezurio BISMS02BI-01 Embedded Intelligent Bluetooth Serial Module** which is the module recommended by Laird Technologies for use with their GW module. The operating modes and functionality of the radio module will be controlled from the MSP430 in the processing sub-system. A primary goal will be to keep data transmission and receiving to a minimum, in order to preserve system power.

For the environmental sensing module, the sub-system messages described in Table 1 are anticipated:

Message	**Message Size (Bytes)**	**Frequency**	**No. Sensors per Gateway**	**Notes**
Environmental Risk	16	12 / hr (max.)	5 (1 for demo)	Message from environmental sensing module to the GW module when an environmental risk occurs or disappears, confidence level changes or disappears.
Environmental sensor status	17	1 / day	5 (1 for demo)	Message from environmental sensing module to the GW module transmitted daily (on receipt of Time Sync message) indicating the status of the environmental sensing module.
Environmental sensor time sync	14	1 / day	5 (1 for demo)	Message from GW module to the environmental sensing module transmitted daily resetting the internal clocks of the sensing modules. It's not entirely clear how the latency of the transmission and reception of this message can be accounted for.

Table 1 : Messages for Environmental Sensing Module

3.1.5 POWER SUB-SYSTEM

For the Smart RRS Primary Safety System environmental sensing module it is intended that the power should all come from an internal battery (no additional power or "topping up" from energy harvesting or scavenging). In order for this to be possible and for the system to maintain functionality over a period of years, a number of criteria must be met, including:

- use a battery which has as high a capacity as reasonably possible;
- wherever possible, use devices (sensors, processor, radio, etc.) capable of low power operation;
- make use of special low power operating modes whenever possible (including switching off devices when they are not required to be on, provided this does not unduly compromise system performance);
- minimize the amount of wireless data transmission and receiving

- minimize wireless transmission power level;
- minimize component (sensors, etc.) excitation levels.

For the particular case of the environmental sensing module, low power operation will be established as follows:

- maintain the MSP430 processor in a low power operating mode commensurate with the other functional requirements listed below;
- maintain the radio sub-system in an “off” state until it is required to wake up (via processor intervention) either: (i) to transmit a module status data packet to (and receive a time synchronization signal from) the GW module (once per day); (ii) to transmit a “hazardous situation present” (and also a “hazardous situation cleared”) data packet to the GW module;
- maintain the environmental sensors in an unpowered state , energizing them only when required to take a measurement (periodicity ~ every 5 minutes: periodicity may change depending on detected situation);
- minimize data processing requirement (use simple algorithms, minimize sampling rates, ADC resolution, etc.);
- transmit sensor data only when a hazardous situation is found to exist (and also when the hazardous situation has cleared).

Detailed analysis of the likely power requirement for the environmental sensing module is given in Section 9.1 (Appendix 4). This analysis indicates that the total average power consumption for the Smart RRS environmental sensing module for the mode of operation specified is expected to be ~ 68 µW with a total average current of ~ 21.8 µA.

Assuming a battery capacity of 2000 mA.hr, the total expected life-time is given by:

Life-time = 2000 / 0.02178 = 91827.4 hrs, or ~ 10.5 years.

A larger battery capacity will obviously give a longer life-time, and should ensure that a sufficiently long life-time is achievable even if the approximate figures used in the calculations above are a factor of a few in error.

3.1.6 FUTURE ENVIRONMENTAL SENSING MODULE SUB-SYSTEM OPTIONS

A number of potential options for enhancing the future functionality of this (and other Smart RRS modules) exist. As noted in Section 3.1 and Section 6 (Appendix 1), the proposed sensors for the demonstration system are a small sub-set of the possible options: future systems could have a wider range of sensors (e.g. humidity, light level, wind-speed, atmospheric pressure, etc.), with more sophisticated algorithms for determining or inferring environmental conditions. These sensor clusters will need enhanced powering through the use (for example) of solar or wind energy harvesting techniques.

A further option would be to make use of local weather forecast services available through the internet: the system could link with these services to enhance the reliability of predictions of local environmental conditions.

3.2 STATIONARY OBSTACLE SENSING MODULE

This sub-system will comprise a battery-powered sensor (reflective optical) for detecting the presence of stationary vehicles (or other stationary objects) in the instrumented section of road. It is intended that this module be mounted on a crash barrier support post, communicating with the GW module via wireless data transmission when a hazardous situation is detected. The transmitted message might simply be a single code meaning “hazard”, or it might differentiate between a limited number of different types of hazard (e.g. “stationary vehicle ahead”, “blockage ahead”, etc.) For the Smart RRS demonstration system, only one stationary obstacle sensing module will be demonstrated. The basic module configuration is shown in Figure 4.

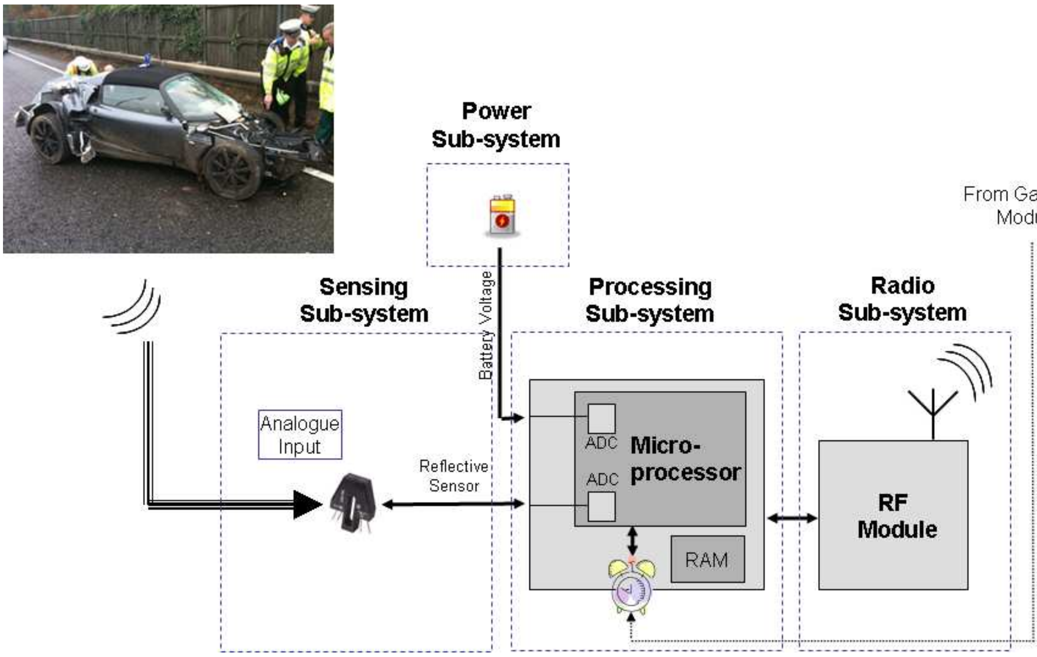

Figure 4 : Stationary Obstacle Sensing Module Configuration

3.2.1 SENSING SUB-SYSTEM

Reliable detection of the presence of stationary vehicles or other obstacles in an instrumented section of road is not a straightforward task, given the additional constraints which apply in the case of the proposed Smart RRS Primary Safety System. These additional constraints include:

- crash-barrier-mounted technology (e.g. no incorporation of sensors into the road itself, which effectively excludes the most commonly-used method for stationary vehicle detection – induction loops buried in the road structure);
- low power operation (the sensing module should be battery-powered);
- continuous operation (this probably makes video cameras ineffective since they won’t operate successfully at night without active lighting, and this would make the power requirement much higher);
- full coverage across the entire length of instrumented road;
- actual (rather than “inferred”) sensing of obstacle presence (i.e. it isn’t considered acceptable to detect the presence of a vehicle as it enters the instrumented section, and then infer that the vehicle must have stopped somewhere by not detecting it

leaving the instrumented zone. In any case, such a system would imply the availability of direct communication between sensor modules in the instrumented section, and this is not desirable either).

The process by which the preferred sensor type for this system has been selected is described in detail in Section 7 (Appendix 2). The sensor technology chosen to be developed for demonstration is based on detection of light emitted by and LED and reflected from stationary objects in the path of the emitted light. A major advantage of this technique in terms of the Smart RRS primary safety system is that, by pulsing the light source, the operating power requirement can be reduced to a sufficiently small level to allow battery operation.

Some initial results using an LED pulsed at 270 Hz, and a photodiode connected to a lock-in amplifier (to remove the effect of ambient light) are shown in Figure 5: these indicate that it is feasible to use the technique to detect both vehicles and other objects in the road in front of the sensing module.

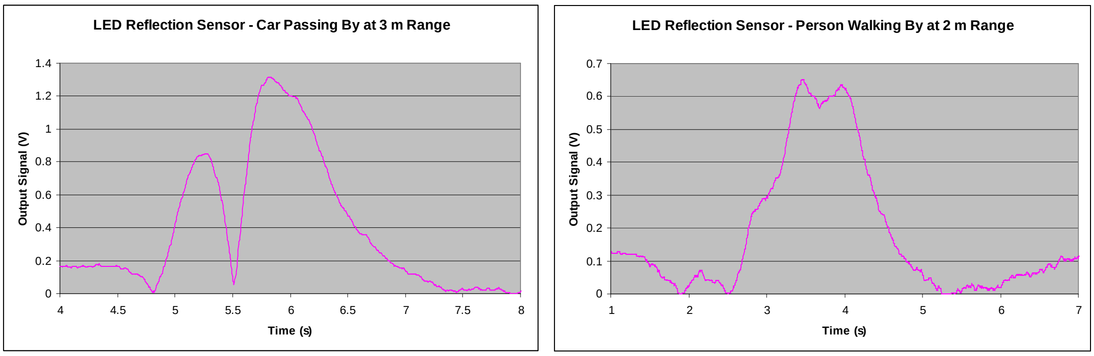

Figure 5 : Example Traces from Reflective Optical Stationary Obstruction Sensor

On-going work will be investigating over what linear and angular ranges the sensor can detect the presence of stationary objects. One concern with the use of an LED is that the achievable operating range may not be sufficient: if this proves to be the case, the use of laser diodes, rather than LEDs, will be investigated.

3.2.2 PROCESSING SUB-SYSTEM

The processing sub-system for the stationary obstruction sensing module will be based on a variant of the **Texas Instruments MSP430** microcontroller family. This sub-system will perform functions similar to those defined for the environmental sensing module above, except that in this case, detection of stationary obstacles will be an “event driven” function (rather than being time driven). Detection by the sensor of a stationary obstacle will trigger the processor into forming an appropriate data packet for transmission by the wireless sub-system. Note that it is anticipated at this stage that the message will indicate only that an obstruction is present, rather than indicate the “type” of obstruction.

3.2.3 RADIO SUB-SYSTEM

As is the case for the environmental sensing module described above, the current intention is that the radio sub-system for the stationary obstruction sensing module will be based on the **Ezurio BISMS02BI-01 Embedded Intelligent Bluetooth Serial Module** (since this sensing module will be communicating with the same GW module).

As before, the operating modes and functionality of the radio module will be controlled from the MSP430 in the processing sub-system, with the primary aim being to preserve system power by minimizing as much as possible the "on" time of the radio sub-system. The sub-system messages described in Table 2 are anticipated:

Message	Message Size (Bytes)	Frequency	No. Sensors per Gateway	Notes
Stationary Obstruction Risk	18	360 (per year estimate)	4	Message from obstruction sensing module to the GW module when an obstruction risk occurs, confidence level changes or disappears.
Stationary Obstruction Status	17	1 / day	4 (2 for demo)	Message from obstruction sensing module to the GW module transmitted hourly (on receipt of Time Sync message) indicating the status of the obstruction sensing module.
Stationary Obstruction Synch.	14	1 / day	4 (2 for demo)	Message from GW module to the obstruction sensing module transmitted hourly resetting the internal clocks of the sensing modules. It's not entirely clear how the latency of the transmission and reception of this message can be accounted for.

Table 2 : Messages for Stationary Obstruction Sensing Module

3.2.4 POWER SUB-SYSTEM

For the Smart RRS Primary Safety System stationary obstruction sensing module it is intended that the power should all come from an internal battery (no additional power or "topping up" from energy harvesting or scavenging). In order for this to be possible and for the system to maintain functionality over a period of years, similar criteria and constraints to those described for the environmental sensing module above will need to be met.

It is not possible at this stage to undertake a detailed calculation of expected power consumption since the sensor itself is still at an early stage of development. The reflective LED concept being investigated has an advantage in that, although the module needs continually to be sensing, the LED itself can be pulsed at a low duty cycle in order to preserve power (in any case, pulsing the LED is required so as to enable the effects of ambient light to be filtered out).

Average power consumption for the processing and radio sub-systems for the stationary obstruction sensor may be slightly reduced from the values calculated for the environmental sensor above, because there are likely to be fewer stationary obstacle risk alerts than there are environmental risk alerts. However, if the same values are assumed, and estimating a value of 500 µA average current for the LED reflection sensor, the total average current (see Section 9.1, Appendix 4) is given by (500 + 10.3 + 1.11) ≈ 511.4 µA. In the absence of any other losses, a 10,000 mA.hr battery would last ~ 2.3 years.

3.3 GATEWAY (GW) MODULE

The GW module forms the hub of the Smart RRS primary safety system local area wireless star network, receiving messages from and sending messages to the sensing modules (via Bluetooth), and transmitting messages to the control centre (via GPRS / GSM).

A detailed description of the requirements for the GW module (which is common to both the primary and tertiary safety systems) is given in Smart RRS Document D5.2 (Tertiary Safety System Architecture Description), and reproduced in Section 8 (Appendix 3) of this document. Specifically in the context of the primary safety system, the GW module needs to perform the following basic functions:

- receive asynchronous wireless messages from either the environmental or the stationary obstacle sensing sub-systems indicating the presence of a hazard in the instrumented crash-barrier zone;
- control the powering on and off of the approaching vehicle radar module and the variable message sign when a hazard situation is detected (n.b. whilst this control function will be useful for preserving power in a real-life system, it is still to be decided whether or not actually to implement it in the demonstration system [or whether just to leave the approaching vehicle radar module and the lap-top pc which is emulating the variable message sign powered all the time]);
- receive signals (possibly hard-wired) from the approaching vehicle radar module;
- control the display of a warning message on the variable message sign when both an approaching vehicle is detected and a hazard situation exists (message may be "general" or "specific to the hazard which exists").

It is assumed that the GW module will always be powered and functioning at least to the extent that it is always able to receive asynchronous messages from the crash-barrier-based sensing modules whenever these occur (radio module in GW module might be in a low power operating mode until it detects an in-coming message). In an eventual commercial system, the GW module is likely to be situated alongside the approaching vehicle radar sensor and the variable message sign: in this case, it is possible that these modules can be hard-wired to the GW (via Ethernet or RS232, for example). However, for the demonstration system, these links will be wireless.

As described in detail in Section 8 (Appendix 3), the Laird Technologies APG Module has been selected for trial in the primary safety system demonstration.

3.4 VARIABLE MESSAGE SIGN (VEHICLE-ACTIVATED DISPLAY EMULATION)

The main aim of the Smart RRS Primary Sensing System is to present a hazard warning via a variable message sign to drivers approaching the instrumented crash barrier section. In a real-life system, the variable message sign will be powered by energy-harvested power (wind, solar): in principle, it need only be powered when there is actually a "hazard" message to display. For the purposes of the demonstration system, the variable message sign will be emulated by a lap-top computer display, because of the practical difficulties of erecting and using an actual variable message sign.

The display will have the following functions.

- Receive data from the GW Module relating to primary system hazard warnings and when to display them.
- Display a variety of messages warning drivers of approaching vehicles of hazards they will shortly encounter. Proposals for the nature of these displays messages are made in the Primary Safety System Requirements document[5].

3.4.1 APPROACHING VEHICLE RADAR SENSOR

The proposal is to use an off-the-shelf low-power Doppler radar unit for this application. In principle (like the variable message sign itself), this sensor only needs to be powered when a hazard situation is detected in the instrumented region of crash barrier (if there is no hazard present, there is no need either to detect on-coming vehicles or to display any sort of message.

An alternative option may be to use a TRW radar module (**TRW ACC 100 radar**) with its CAN output converted to a more convenient form (e.g. RS232). However, the facts that the TRW ACC 100 radar unit draws a current of ~ 240 mA at 12 V supply and that it is expected to take a few seconds to reach a fully-operational state from switch-on mean that this device may not be suitable for the primary safety system demonstration.

When an on-coming vehicle is detected and a hazard situation is present, a warning sign is displayed on the variable message sign. Since this radar sensor will be mounted close to the GW module, it is likely to be hard-wired (RS232 or Ethernet) directly into the gateway rather than communicating via wireless transmission.

3.4.2 POWER SUB-SYSTEM

For a real-life system, the variable message sign and approaching vehicle radar sensor will be powered by a combination of battery and energy-harvested power. The precise details of powering for the demonstration system are **still to be decided,** although it is anticipated that a commercial off-the-shelf power scavenger will be used – probably a solar panel or wind / solar combination.

3.5 CONTROL CENTRE MODULE DESCRIPTION

The control centre is likely to undertake the following functions:

- Receive data via the GW module.
- Store the data arriving from the sensing modules via the GW module for future analysis.
- Displaying events and status of various parts of the system (sensing modules, GW module) in such a way as successfully to demonstrate the system.
- Provide a means for displaying simulated warning signals generated by data from the sensing modules.

If time and budget allow, there may be some mechanism (e.g. a web-site) that enables the simulated warning signals to be made available to road users for the purposes of demonstration.

[5] Smart RRS deliverable D4.1 – Requirements for the Primary Safety System

The system shall be built from off the shelf components and systems but will require additional software to be written.

4. MODULE-TO-MODULE INTERFACE REQUIREMENTS

The proposed distribution of the Smart RRS safety systems is as shown schematically in Figure 6 (note that this diagram includes both tertiary and primary safety system elements).

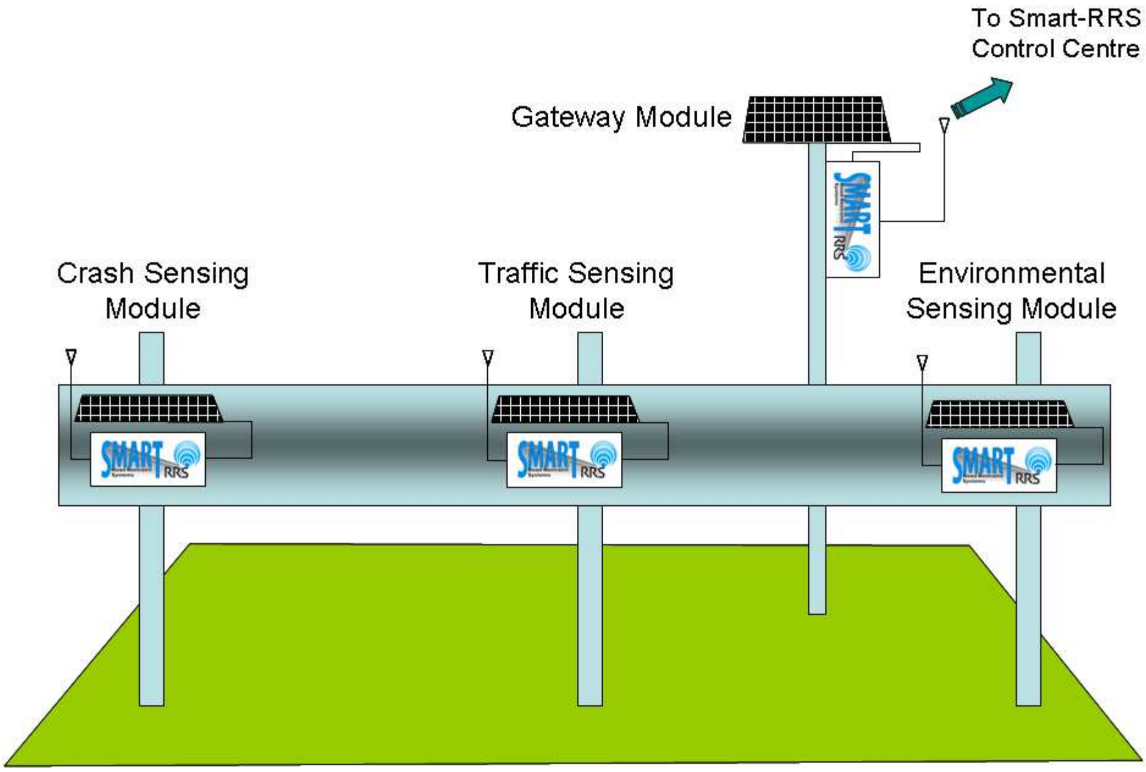

Figure 6 : Smart RRS Safety System Distribution

For the primary safety system, the main "lines of communication" are between:

- The instrumented road "environment" and the sensing modules
- The sensing modules and the GW module (and vice versa)
- The GW module and the control centre

As noted in Section 2, the communications topology will be a star network with the GW module as the hub. As also stated, there is no direct communication between sensing modules, or between the control centre and an individual sensing module (in a real-life system, all control centre messages will pass via the GW module: note that this functionality will not be implemented in the demonstration system).

4.1 ROAD ENVIRONMENT TO SENSING MODULE

Hazardous situations (dangerous environmental conditions or the presence of stationary obstacles) occurring in the instrumented road environment are detected by the sensing modules, and communicated to the GW module. Particularly in the case of the stationary obstruction sensing module, the sensor needs to be able to "see" the road environment itself, and this places some constraints on the positioning of the sensing module, in addition to those outlined in Section 1.2 above.

The most likely place for attachment of the sensing modules to the crash barrier structure is at the top of, and either behind (in the case of the environmental sensing module) or to one side of (in the case of the stationary obstruction sensing module) the crash barrier support post (note that the temperature sensing part of the environmental sensing module may be separately housed in an enclosure positioned towards the base of the crash barrier support post).

It is unlikely that it will be feasible to house the primary safety system sensing modules within the crushable part of the Smart RRS crash barrier,

Another question that arises regarding the architecture of the system is the spacing of the primary sensing modules, particularly the stationary obstruction sensing modules. From a system cost point of view, the greater the spacing between sensing modules, the better. On the other hand there must be sufficient sensors along the rail to ensure that the entire instrumented road area is covered. The stationary obstruction sensors will be designed with a nominal detection range of 10 m, so that this also will define the required spacing of sensing modules. The suitability of this value for sensing module spacing will be investigated through the project.

4.2 SENSING MODULE TO GATEWAY (GW) MODULE

Communication between the sensing module and the GW module will be via Bluetooth wireless for the demonstration system. It is anticipated that the following signals will need to be transmitted from the sensing module to the GW module:

- Signals relating to a hazardous situation arising:
    - Time of event
    - Location / identification of sensing module(s) (note that this will also distinguish between “environmental” and “stationary obstruction” types of hazard)
    - Possibly code relating to the specific type of hazard involved (e.g. “ice”, “wet road surface”, stationary vehicle”, etc.) This will depend on the selected sensor signal characteristics and processing. Note that this is currently not included in the “Message Requirements” listed in Table 3 in Section 8 – Appendix 3)
- Regular diagnostic updates (once per hour?)
    - Time of update
    - Location / identification of sensing module(s)
    - Additional diagnostic measurement data (e.g. battery voltage)

Details of the message characteristics and requirements associated with this various signal types may be found in Table 3 (Section 8 – Appendix 3).

4.3 GATEWAY (GW) MODULE TO CONTROL CENTRE

The GW module will transmit the following types of message to the control centre, via GPRS / GSM:

- System status updates.

4.4 CONTROL CENTRE TO GATEWAY (GW) MODULE

- Future implementations of the system may have the capability of transmitting messages (for example, requests for additional and / or diagnostic data) via GPRS / GSM from the control centre to the GW module (and hence from the gateway to the sensing modules). However, it is not intended that this functionality will be implemented in the demonstration system.

4.5 GATEWAY (GW) MODULE TO SENSING MODULE

The GW module will communicate with any / all its associated sensing modules as required. The following types of messages will be transmitted from the GW module to the sensing module(s):

- Status requests (once per day updates).
- Time synchronization data (to be communicated to the sensing module when the sensing module makes a status update).

5. CONCLUSION

This document has reviewed the requirements for the Smart RRS primary safety system and from these has proposed a system implementation based around a GW module monitoring the output of a number of environmental and stationary obstruction sensing modules. The sensing modules are arranged as a star network with the gateway, all communications taking place through the gateway at the hub of the network.

The key modules for the system are the sensing modules ("environmental" and "stationary obstruction"), the GW module, a control centre, an emulation of a vehicle-activated variable message display sign, and an approaching vehicle radar sensor.

The sensing modules detect the occurrence of potentially hazardous situations. The gateway forms the communications hub for the system, receiving messages from (and transmitting messages to) the sensing modules and the variable message sign, the latter being the means by which oncoming traffic is warned that a potentially hazardous situation exists.

The proposed sensing modules comprise the sensors themselves (a combination of temperature, relative humidity, and rain sensors in the case of the environmental sensing module, and an optical reflective sensor in the case of the stationary obstruction sensing module); a processing sub-system to run algorithms for interpreting the received sensor data as well as controlling the power and communications sub-systems; a radio sub-system to enable wireless communication using a wireless personal area network (WPAN) protocol with the gateway; and a power sub-system to provide long-term power to the sensing modules. The document argues that these sensing modules should be mounted on the posts of the crash barrier.

The GW module monitors the sensing modules using a WPAN protocol and communicates to a remote control centre using GPRS. In addition to communication functions, the GW module also provides some logic for controlling the vehicle-activated variable message sign, based on data from the sensing modules combined with detection of approaching vehicles. The GW module also has the function of providing some time synchronization for the sensing modules.

The control centre receives and stores status data from the sensing modules and provides means for examining this data.

A more detailed design description will be given in the Smart RRS Primary Safety System Design Document, Smart RRS deliverable D4.3.

6. APPENDIX 1: DETAILED DISCUSSION OF SENSOR OPTIONS FOR ENVIRONMENTAL SENSING MODULE

Temperature Sensing

Option 1 (recommended): For demonstration, it is proposed that the environmental module should measure air temperature close to the road (rather than actual road surface temperature). To do this, an IC-type temperature sensor such as one of the following will be suitable:

- National Semiconductor LM60 Temperature Sensor;
- Analog Devices AD592 Temperature Transducer.

Both are low power, linear, single supply rail devices: the LM60 is a three-wire device with a voltage output that is capable of operating from a 2.7 V supply; the AD592 is a two-wire device with a current output.

It is proposed that one or other of these devices will be housed in a small enclosure (rated to at least IP54) fixed close to the base of a crash barrier support post, with a cable attaching the sensor to the main environmental sensing module higher up the post.

Option 2: It may be considered desirable to measure actual road surface temperature in the instrumented region. For this purpose, remote IR temperature sensors are available, such as the **IR100 and IR120 Infra-red Remote Temperature Sensors** supplied by **Campbell Scientific**, or the **DST111 Remote Road Surface Temperature Sensor** supplied by **Vaisala** (see data sheets in the Appendix). Both of these devices will provide a measurement of the actual road surface temperature, which is potentially advantageous in trying to determine conditions which are truly hazardous (as opposed to “potentially” hazardous). However, there are a number of negative aspects to the use of such devices:

- they are expensive (for example, the IR100 and IR120 from Campbell Scientific cost respectively £560 and £476 for the sensors alone: with a protective enclosure, they cost even more);
- they are intended for use with proprietary data loggers, and hence interfacing with the Smart RRS processing module is less straightforward;
- powering is more complex (for example, whilst they are relatively low power devices, the Campbell Scientific IR100 and IR120 require a negative voltage rail: the Vaisala DST111 operates from a single supply rail of 9 to 30 V, but with a relatively high power consumption of 33 mW);
- whilst such devices are potentially capable of high resolution and accurate temperature measurement, compensating for extraneous effects (such as the non-black-body emissivity of road surfaces) is complicated, and errors caused by inaccurate compensation can lead to false temperature measurements.

For these reasons, the simpler Option 1 alternative for temperature measurement outlined above is recommended for the demonstration Smart RRS environmental sensor module.

Rain Detection

A number of different types of sensor for detecting the occurrence of rain or other forms of environmental precipitation are available. Devices based on either “tipping buckets” or expanding hygroscopic discs are used (for example) for automatic control of sprinkler systems. Amongst the difficulties associated with these devices as regards their use in the Smart RRS environmental sensing module are the facts that they require a significant amount of rain to fall (≥ 0.25 mm) before they “trip”, and then take an uncertain amount of time to “dry out” again. Other devices based on total internal reflection characteristics at a glass-air interface (as used, for example, in vehicle automatic windscreen wiper systems) are not really suitable for the Smart RRS application

The recommended sensor type for this application is the so-called “leaf wetness” sensor which is primarily intended to provide an indication of wetness conditions in leaf canopies. These devices typically comprise a simple resistive grid, the resistance of which is modified by the presence and amount of water on the surface of the grid. Capacitive / dielectric constant versions of the sensor are also available. One of the following devices is recommended:

- The Campbell Scientific Model 237 or 237F Leaf Wetness Sensor;
- The Decagon Leaf Wetness Sensor
- The LWS1-R2-B Leaf Wetness Sensor supplied by Hobby Board Electronics
- Data sheets for these devices are included in the Appendix.

The Campbell Scientific 237 and 237F sensors are both resistive grid devices. The 237 LWS consists of a rigid epoxy circuit board with interlacing gold-plated copper fingers. The 237F LWS is similar but with a flexible polyamide film circuit which allows it to be easily attached to uneven surfaces. Condensation or rain on the sensor lowers the resistance between the fingers. Droplets small enough not to touch two fingers simultaneously do not change the sensor resistance. The 237F LWS has a very small spacing between the fingers (0.25mm), which makes it very sensitive to fine droplets. Though they are intended to be used with a Campbell Scientific data logger (which provides the sensor excitation and signal interpretation), the sensor itself is simply a resistive bridge device, so can easily be powered and read / processed in the type of system proposed for the Smart RRS environmental sensor module application. The instruction manual that goes with these sensors provides notes on how to interpret the output in terms of the amount of “wetness”. The 237 LWS device costs £71, whilst the 237F LWS costs £18.

The Decagon LWS measures the changing dielectric constant of the upper surface of the sensor in the presence of moisture, water or ice. Again the instruction manual includes details of how to interpret the output voltage signal from this device. It is a low-power device, operating from a DC supply of 2.5 to 5 V, and current of a few mA. The device is available from Campbell Scientific at a cost of £110.

The Hobby Board Electronics LWS1-R2-B LWS is sold for $2 as a stand-alone PCB with only the interlaced conductive fingers on the board. This is intended to be connected to a 1-wire moisture meter board also supplied by Hobby Board Electronics, but could instead easily be incorporated in a “home-made” bridge configuration for moisture / rain detection.

Use of the above devices will enable at least the detection of rainfall for the environmental sensor module. Further interpretation of the sensor data may also enable other parameters to be measured or inferred, such as the presence of ice (since the dielectric constant of ice is different to that of water, the Decagon LWS can potentially differentiate between the presence of liquid water and ice) or the duration of precipitation.

One further rain sensor option is the **Campbell Scientific RD01 Rain Detector** (see data sheet in the appendix). Like the Decagon LWS, this provides an indication of the presence of rain by capacitive measurement. This is a much more sophisticated instrument than the various leaf wetness sensors identified above (and, as a consequence, is much more expensive - £745). In principal the sensor is able to provide an indication both of precipitation presence and intensity: it is able to infer when a rainfall event has ended, but this depends to some extent on the operation of an internal heater which makes the power consumption much higher. In general, for the case of the Smart RRS environmental sensing module, any advantages this device may offer in terms of the improved performance do not seem to justify the additional cost and complexity.

7. APPENDIX 2: DETAILED DISCUSSION OF SENSOR OPTIONS FOR STATIONARY OBSTRUCTION SENSING MODULE

To assess the options available for doing the stationary obstruction sensing task, the Analytical Hierarchical Process (AHP) has been used. AHP is a structured technique used to help determine the best solution to a complex decision. In Smart RRS, it has already been used to determine the best sensor technology option for the Tertiary Safety System. The same process has now been used to determine the best sensor technology option for the stationary obstruction sensing task.

The following sensor types were considered in the AHP evaluation:

	1	2	3	4	5	6	7	8	9
Technol-ogy Name	Doppler-type µwave Radar - TRW	Doppler-type µwave Radar - non-TRW	Time-of-flight µwave Radar	Camera - TRW	Time-of-flight LIDAR	Scanne-d / Imaged LIDAR	Ultrason-ic Reflection	LED Reflect-ion	Magnet-ometer

These sensor types were evaluated against the following criteria (note that some of the constraints above were considered as “gateway” criteria – e.g. road-mounted induction loop was not considered as a viable sensor technology option for this application):

1	Bill of Materials / Complexity	Lower BOM (less complexity) considered better
2	Separation of Sensors	Fewer sensors required to cover full range considered better
3	Power Requirement	Lower power requirement considered better
4	TRW Technology Content	Higher TRW technology content considered better
5	Detection Resolution	Higher resolution considered better
6	Insensitivity to Extraneous Effects	Greater insensitivity considered better
7	Development Resource Requirement	Lowe development resource requirement considered better

The results of the AHP evaluation are shown in Figure 7.

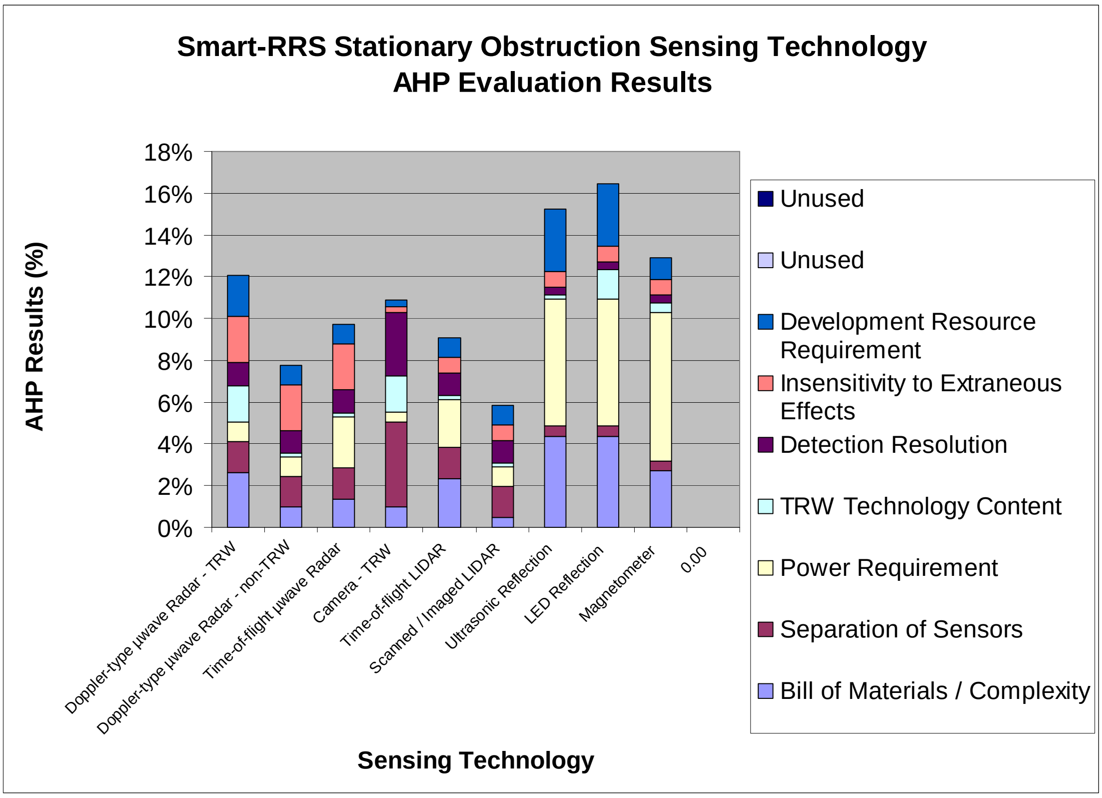

Figure 7 : Results of AHP Evaluation of Stationary Obstruction Sensing Technologies

The results suggest that the LED reflection and ultrasonic reflection techniques are best suited to this application. They score particularly well against two of the criteria – power requirement and BOM / complexity, and these factors outweigh other ones such as the fact that either of these techniques will require some development effort within the Smart RRS programme. Other techniques which score quite well are the magnetometer, and the two already-available TRW sensors – microwave radar and camera. These latter two both do poorly as regards the power requirement criterion, the camera because it will require active lighting to enable it to work at night, and the microwave radar because it is not designed for low-power battery operation.

Currently, therefore, the decision has been taken to evaluate experimentally the reflective LED sensing technique.

8. APPENDIX 3: DETAILED DISCUSSION OF GATEWAY (GW) MODULE OPTIONS AND SELECTION

8.1 GATEWAY MODULE REQUIREMENTS

The GW module is intended to aggregate data from a group of sensing modules in its vicinity using an appropriate wireless personal area network (WPAN) or local area network (WLAN) protocol. It then communicates this data to the control centre module via a long distance communication technique such as GSM-based technology.

The aim is to purchase an "off-the-shelf" GW module for the Smart RRS demonstration systems. A number of suppliers of such modules have been identified. Evaluation of the different product offerings is currently on-going to identify the best option.

8.1.1 INSTALLATION FUNCTIONAL REQUIREMENTS

Ideally, there will be a mode for installation during which each sensing module can be identified, located and registered in a database (both at the GW module and the control centre). Automation of this process would be beneficial, but this might involve the integration of a GPS receiver in each sensing node. It is likely that this process will be carried out semi-manually (e.g. the installer entering location and identification code of each node into a PDA or the like) with the data being uploaded into the system prior to it's becoming live.

In addition to the system knowing the location of each sensing module, the communication network between the sensing module and the GW module needs to be set up. The exact nature of this task depends on the particular wireless protocol chosen.

8.1.2 OPERATIONAL FUNCTIONAL REQUIREMENTS

This section lists the top level operational functional requirements for the GW module. Note that the GW module is common to both the Tertiary and the Primary Smart RRS safety systems. Thus, some of the requirements are more appropriate (or, indeed, only appropriate) to one or other of these safety systems.

GFR1 The GW module shall be capable of communicating with up to 25 sensing modules.

GFR2 The GW module shall be capable of an aggregate communication bandwidth with the sensing modules of at least 1 kbit s^{-1}.

GFR3 The GW module and the sensing modules shall form a star network with the GW module as the hub or centre of the star.

GFR4 The GW module shall be capable of sending data to and receiving data from the following sensing modules: a crash sensing node, an environmental sensing module and an obstruction sensing module

GFR5 The GW module shall be capable of maintaining a time reference (Accuracy to be determined through the course of the project). It will be necessary to determine if it is sufficient just to communicate a single clock timing to the sensing nodes and for the control centre to monitor these and make allowances for GW module clock drift).

GFR6 The GW module shall receive daily status requests from, and at the same communicate time sync data to, each sensing module (The spacing of these events across a day will be determined through the project).

GFR7 The GW module shall receive event or risk data from each sensing module and communicate that immediately to the control centre.

Figure 8 illustrates the operation of the GW module in normal operation. Note that, for the demonstration system, it is not intended that communication from the control centre to the GW module will be demonstrated. In a real system, the ability to make such communication may be necessary. For example, it will be necessary to "cancel" a displayed message indicating that a crash event has occurred once the carriageway has been cleared (as indicated in Figure 8): in a real system, such a cancellation request is likely to come from the remote control centre, being passed via the GW module to the display sign. For the demonstration system, this functionality is likely to be implemented simply via a "cancel display" button on the vehicle-activated display emulation (lap-top).

Situations can also be envisaged where it might be useful for requests for "additional data" to be sent from the GW module to one or more sensing modules at times other than the normal "once-per-day" intervals. This functionality will not be implemented in the demonstration system, however.

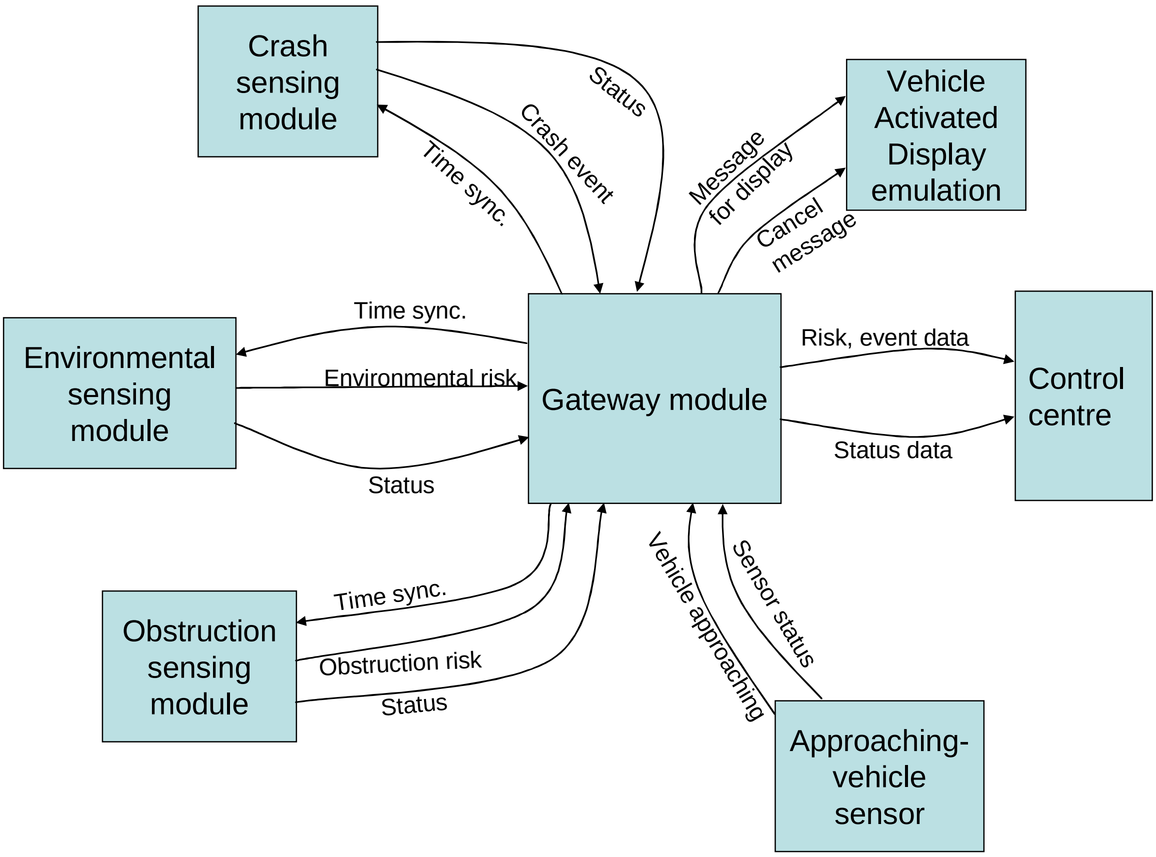

Figure 8: Gateway Message Traffic in Normal Operation

8.1.3 SERVICE FUNCTIONAL REQUIREMENTS

GFR8 The GW module shall generate its own status information which it will communicate back to the control centre along with the status information of the other modules.

Note that no specific service mode is envisaged for the purposes of the demonstration system.

8.1.4 OTHER REQUIREMENTS

Size and location requirements

GOR1 There shall not be more than 5 GW modules per kilometre.

GOR2 The GW modules shall be located such that they can communicate with a control centre (for a GSM-based system this implies within line-of-sight and range of a GSM basestation).

Resource requirements

GOR3 The GW module shall make minimal demands on the wired infrastructure for power.

GOR4 The gateway shall make minimal demands on the wired infrastructure for communications with road users and traffic control centres.

The requirement GOR3 implies that battery and / or power scavenging techniques will be required for the system. Requirement GOR4 implies a wireless communications system.

Environmental Requirements

GOR5 The GW module shall be designed to withstand the roadside environment for the duration of the demonstration.

Economical Requirements

No specific requirements are given but the design process shall bear in mind that that this is to be a low-cost system.

8.2 GATEWAY (GW) MODULE SUB-SYSTEMS – REQUIREMENTS, CONSTRAINTS AND OPTIONS

A simplified diagram of the Smart RRS GW Module generic architecture is shown in Figure 9.

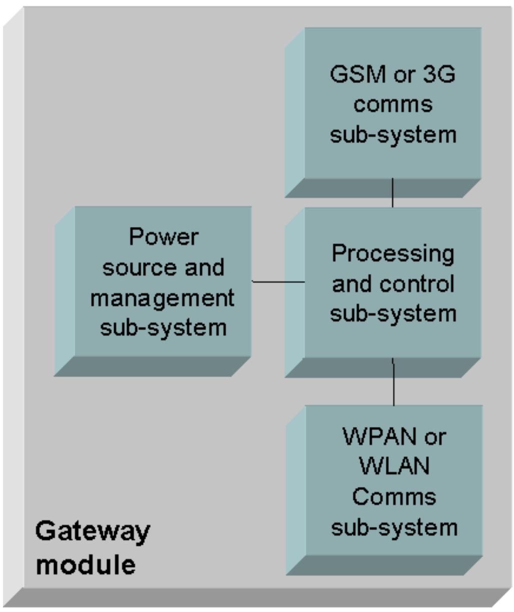

Figure 9 : Gateway Module Generic Architecture

The GW module will interface with the sensing modules using a wireless RF protocol, effectively operating as a personal or local area network.

Long range connection to the control centre will be using standard mobile phone technology (GSM / GPRS).

At present, it is anticipated that the processing tasks of the GW module will be relatively limited. Its primary tasks will be to pass data between the sensing modules and the control centre, and to maintain time synchronisation between itself and the sensing modules.

The GW module links wirelessly to several sensing modules on the one hand, and to the system control centre on the other. It therefore has to receive the data from the various sensing modules, manipulate it appropriately (for example, remove any overhead data, and – possibly – undertake additional data processing in addition to that done at the Sensing Module), and present the data as appropriate for transmission to the Control Centre. The GW Module may also act in the reverse direction: to transmit signals or commands sent from the Control Centre to the Sensing Modules to control their operation. Data communications may be via one or more types of RF link.

These main tasks of the GW Module are discussed in more detail below.

8.2.1 CONTROL OF SENSING MODULES

Each GW Module acts as the 'access point' for the Sensing Modules in its vicinity. It controls "membership" of the Sensing Modules to its "local" wireless network and manages local security. Assuming a wireless link between the GW Module and the local Sensing Modules (and also assuming no wireless communication between Sensing Modules), the number of Sensing Modules handled by each GW Module will depend on the maximum wireless transmission range. This document defines the maximum number of Sensing Modules per GW Module as 25 (see GFR1 in Section 8.1.3): for example, assuming a maximum wireless transmission range of 50 m and a Sensing Module spacing of 4 m, each GW Module will (in principle) control 25 Sensing Modules in a star network formation (also a requirement – see GFR3 in Section 8.1.3).

Any configuration information for the Sensing Modules will also be generated by, or relayed through, the GW Module. Some of this may be autonomously handled by the radio PHY and MAC (for example, autonomous control of the RF transmitted power), but other higher-level information (for example, calibration values for sensors or control instructions to start and stop the Sensing Modules) will be handled by GW Module.

8.2.2 DATA RECEPTION, PROCESSING AND FORWARDING

The data received at the GW Module from the Sensing Modules will need to be processed to remove any unnecessary overhead information. This might include error correction, decryption, de-compression or other signal processing functions. Again, some of these functions (for example, error correction) may reside in the radio PHY and MAC layers, but others will need to be provided by the GW Module. The processed data will then be forwarded to the system Control Centre.

8.2.3 SYNCHRONIZATION

The reference clock for the system will be contained within, or referenced by, the GW Module. Multiple GW Modules within a complete system will also need to be synchronized (for demonstration purposes, this might be managed by a single 'master'

GW Module). Each GW Module will then communicate with its local Sensing Modules as appropriate, to enable all clocks on the Sensing Modules to be synchronized to the reference.

8.2.4 BULK STORAGE

If required or desirable (perhaps for demonstration purposes), the GW Module could potentially provide fixed or removable data storage capacity.

8.2.5 DATA FLOWS

In order to estimate the amount of data traffic each GW module must handle, Table 3 has been constructed. Note that this table covers the GW message requirements for all types of sensor module (that is, primary safety system environmental and traffic obstruction sensing message requirements as well as those associated with the tertiary safety system). The table is not definitive for the system – only a tool to provide an estimate for the amount of data traffic.

Message	Data	Data size (Bytes)	Message Size (Bytes)	Frequency (hr^{-1})	No. Sensors per Gateway	Notes
Crash Event			15	1.1E-04	10	Message from crash sensing module to the GW module when a crash event occurs.
	Message ID	1				Code that identifies this message as a crash event.
	Packet ID	1				Identifier for this instance of this message. A bit like the rolling counter, it's not clear how important this is for these single packet messages.
	Sensor ID	1				Code uniquely identifying the crash sensing module. 1 byte is more than enough for the project – but once we get into volume production…!
	Gateway ID	1				Code uniquely identifying the gateway to which the message is being sent. It's not clear whether this is needed at this stage.
	Time	7				HHMMSSS where the least significant byte (LSB) is 10ths of seconds. 24 hour clock. We felt that date information is not needed at this point in the system and that there should be a way of resolving any ambiguities occurring at the midnight rollover. Could be binary encoded into 3 bytes if we are getting really precious about message size. Date stamping would more likely take place on receipt of the message at the control centre.

Message	Data	Data size (Bytes)	Message Size (Bytes)	Frequency (hr^{-1})	No. Sensors per Gateway	Notes
	Magnitude	1				A 0…255 indicator of the magnitude of the crash – e.g. related to the maximum displacement during a crash event. Note that we felt that for development purposes, the raw acceleration data could be stored on board the sensor for later download. We need to define functionality to do this.
	FEC	2				Forward error correction
	Rolling Counter	1				Not clear this is needed where messages are “1 off’s” like this one?
Crash Sensor Status			17	1	10	Message from crash sensing module to the GW module transmitted hourly (on receipt of Time Sync message) indicating the status of the crash sensing module.
	Message ID	1				Code that identifies this as a Status message from a crash sensing module.
	Packet ID	1				Identifier for this instance of this message.
	Sensor ID	1				Code uniquely identifying the crash sensing module.
	Gateway ID	1				Code uniquely identifying the gateway to which the message is being sent. It’s not clear whether this is needed at this stage.
	Time	7				HHMMSSS where LSB is 10ths of seconds. 24 hour clock. We felt that date information is not needed and that there should be a way of resolving any ambiguities occurring at the midnight rollover.
	Battery Voltage	1				Binary representation of the battery voltage.
	Sensor status	1				Byte identifying any error codes from the acceleration sensor (single byte should cover all three axes).
	Solar charge status	1				Whether the solar cell is providing any charging current.
	FEC	2				Forward error correction

Message	Data	Data size (Bytes)	Message Size (Bytes)	Frequency (hr^{-1})	No. Sensors per Gateway	Notes
	Rolling Counter	1				Not clear this is needed where messages are “1 off’s” like this one?
Crash sensor time sync			14	1	10	Message from GW module to the crash sensing module transmitted hourly resetting the internal clocks of the sensing modules. It’s not entirely clear how the latency of the transmission and reception of this message can be accounted for.
	Message ID	1				Code that identifies this as a Status message from a crash sensing module.
	Packet ID	1				Identifier for this instance of this message.
	Sensor ID	1				Code uniquely identifying the crash sensing module to which the message is being sent.
	Gateway ID	1				Code uniquely identifying the GW from which the message is being sent. It’s not clear whether this is needed at this stage.
	Time	7				HHMMSSS where LSB is 10ths of seconds. 24 hour clock. We felt that date information is not needed and that there should be a way of resolving any ambiguities occurring at the midnight rollover.
	FEC	2				Forward error correction
	Rolling Counter	1				Not clear this is needed where messages are “1 off’s” like this one?
Environmental risk			16	12	5	Message from environmental sensing module to the GW module when an environmental risk occurs, confidence level changes or disappears.
	Message ID	1				Code that identifies this message as an environmental risk alert.
	Packet ID	1				Identifier for this instance of this message. A bit like the rolling counter, it’s not clear how important this is for these single packet messages.
	Sensor ID	1				Code uniquely identifying the environmental sensing module. 1 byte is more than enough for the project – but once we get into

Message	Data	Data size (Bytes)	Message Size (Bytes)	Frequency (hr^{-1})	No. Sensors per Gateway	Notes
						volume production…!
	Gateway ID	1				Code uniquely identifying the gateway to which the message is being sent. It's not clear whether this is needed at this stage.
	Time	7				HHMMSSS where LSB is 10ths of seconds. 24 hour clock. We felt that date information is not needed and that there should be a way of resolving any ambiguities occurring at the midnight rollover. Could be binary encoded into 3 bytes if we are getting really precious about message size.
	Risk Type	1				Potential for 256 messages
	Risk Confidence	1				0…255 confidence level indicator for the particular risk type. 0 = clear this risk.
	FEC	2				Forward error correction
	Rolling Counter	1				Not clear this is needed where messages are "1 off's" like this one?
Environmental sensor status			17	1	5	Message from environmental sensing module to the GW module transmitted hourly (on receipt of Time Sync message) indicating the status of the environmental sensing module.
	Message ID	1				Code that identifies this as a Status message from an environmental sensing module.
	Packet ID	1				Identifier for this instance of this message.
	Sensor ID	1				Code uniquely identifying the environmental sensing module.
	Gateway ID	1				Code uniquely identifying the gateway to which the message is being sent. It's not clear whether this is needed at this stage.
	Time	7				HHMMSSS where LSB is 10ths of seconds. 24 hour clock. We felt that date information is not needed and that there should be a way of resolving any ambiguities occurring at the midnight rollover.
	Battery Voltage	1				Binary representation of the battery voltage.

Message	Data	Data size (Bytes)	Message Size (Bytes)	Frequency (hr^{-1})	No. Sensors per Gateway	Notes
	Sensor status	1				Byte identifying any error codes from the various environmental sensors.
	Solar charge status	1				Whether the solar cell is providing any charging current.
	FEC	2				Forward error correction
	Rolling Counter	1				Not clear this is needed where messages are “1 off’s” like this one?
Environmental sensor time sync			14	1	5	Message from GW module to the environmental sensing module transmitted hourly resetting the internal clocks of the sensing modules. It’s not entirely clear how the latency of the transmission and reception of this message can be accounted for.
	Message ID	1				Code that identifies this as a Status message from an environmental sensing module.
	Packet ID	1				Identifier for this instance of this message.
	Sensor ID	1				Code uniquely identifying the environmental sensing module to which the message is being sent.
	Gateway ID	1				Code uniquely identifying the gateway from which the message is being sent. It’s not clear whether this is needed at this stage.
	Time	7				HHMMSSS where LSB is 10ths of seconds. 24 hour clock. We felt that date information is not needed and that there should be a way of resolving any ambiguities occurring at the midnight rollover.
	FEC	2				Forward error correction
	Rolling Counter	1				Not clear this is needed where messages are “1 off’s” like this one?
Obstruction			18	360	4	Message from obstruction sensing module to the GW module when an obstruction risk occurs, confidence level changes or disappears.
	Message ID	1				Code that identifies this message as an obstruction risk alert.

Message	Data	Data size (Bytes)	Message Size (Bytes)	Frequency (hr^{-1})	No. Sensors per Gateway	Notes
	Packet ID	1				Identifier for this instance of this message. A bit like the rolling counter, it's not clear how important this is for these single packet messages.
	Sensor ID	1				Code uniquely identifying the obstruction sensing module. 1 byte is more than enough for the project – but once we get into volume production…!
	Gateway ID	1				Code uniquely identifying the gateway to which the message is being sent. It's not clear whether this is needed at this stage.
	Time	7				HHMMSSS where LSB is 10ths of seconds. 24 hour clock. We felt that date information is not needed and that there should be a way of resolving any ambiguities occurring at the midnight rollover. Could be binary encoded into 3 bytes if we are getting really precious about message size.
	Risk Type	1				Potential for 256 messages
	Risk Velocity	2				Value representing the speed at which the obstruction is travelling (not sure if this is needed but let's put it in for the time being).
	Risk Confidence	1				0...255 confidence level indicator for the particular risk type. 0 = clear this risk.
	FEC	2				Forward error correction
	Rolling Counter	1				Not clear this is needed where messages are "1 off's" like this one?
Obstruction sensor status			17	1	4	Message from obstruction sensing module to the GW module transmitted hourly (on receipt of Time Sync message) indicating the status of the obstruction sensing module.
	Message ID	1				Code that identifies this as a Status message from an obstruction sensing module.
	Packet ID	1				Identifier for this instance of this message.
	Sensor ID	1				Code uniquely identifying the obstruction sensing module.

Message	Data	Data size (Bytes)	Message Size (Bytes)	Frequency (hr^{-1})	No. Sensors per Gateway	Notes
	Gateway ID	1				Code uniquely identifying the gateway to which the message is being sent. It's not clear whether this is needed at this stage.
	Time	7				HHMMSSS where LSB is 10ths of seconds. 24 hour clock. We felt that date information is not needed and that there should be a way of resolving any ambiguities occurring at the midnight rollover.
	Battery Voltage	1				Binary representation of the battery voltage.
	Sensor status	1				Byte identifying any error codes from the obstruction sensor.
	Solar charge status	1				Whether the solar cell is providing any charging current.
	FEC	2				Forward error correction
	Rolling Counter	1				Not clear this is needed where messages are "1 off's" like this one?
Obstruction sensor time sync			14	1	4	Message from GW module to the obstruction sensing module transmitted hourly resetting the internal clocks of the sensing modules. It's not entirely clear how the latency of the transmission and reception of this message can be accounted for.
	Message ID	1				Code that identifies this as a Status message from an obstruction sensing module.
	Packet ID	1				Identifier for this instance of this message.
	Sensor ID	1				Code uniquely identifying the obstruction sensing module to which the message is being sent.
	Gateway ID	1				Code uniquely identifying the gateway from which the message is being sent. It's not clear whether this is needed at this stage.
	Time	7				HHMMSSS where LSB is 10ths of seconds. 24 hour clock. We felt that date information is not needed and that there should be a way of resolving any ambiguities occurring at the midnight rollover.

Message	Data	Data size (Bytes)	Message Size (Bytes)	Frequency (hr^{-1})	No. Sensors per Gateway	Notes
	FEC	2				Forward error correction
	Rolling Counter	1				Not clear this is needed where messages are "1 off's" like this one?

Table 3 : Gateway (GW) Module Message Formats and Requirements

Multiplying all the message sizes by their corresponding frequency of transmission and number of sensing nodes per gateway together and adding them all up gives a data rate of about 61 bit s^{-1}. This is extremely low and allows for the choice from among a wide range of low bandwidth wireless technologies to communicate with the sensing modules.

8.3 GATEWAY (GW) MODULE SUPPLIERS

A comprehensive review of suppliers has revealed two (possibly three) who seem to have GW module products which are suitable for the proposed Smart RRS demonstration systems. Note that this has also driven the choice of radio module protocol for use with these GW modules. At present, the favoured choice of GW module is the APG supplied by Laird Technologies. This choice is largely driven by availability within the project timescales. This module currently incorporates Bluetooth wireless modules, and this drives the choice of wireless protocol for the rest of the Smart RRS system also down the Bluetooth route. It should be noted that the Laird Technologies APG module is a new product, and future implementations are intended which will use alternative wireless protocols which may be more suitable than Bluetooth for the Smart RRS applications. Should this product not prove appropriate other options, including ones from Adaptive Wireless and Libelium may be considered.

A short summary of the results of the investigation into potential suppliers of suitable gateway products is given in Table 1. From this investigation, the Laird Technologies APG Module has been selected for trial. Laird Technologies have kindly loaned us one of their modules to enable us to undertake some experimental investigation into its performance (although note that the GSM / GPRS functionality is not currently enabled in the device: it is a new product and not finally released for production yet – release date expected to be in March 2011).

Supplier	System	COTS?	UK Base?	Notes
Apoideas	Low-power GPRS sensor nodes (no intermediate gateway)	No - development kit only	Yes	The sensor nodes transmit directly via GPRS to control centre (no intermediate GW module). Apoideas have low-power technology for such a system. Questions over speed of connection (for Smart RRS primary system requirements)?
Adaptive Wireless Solutions	E-Senza integrated GW module and wireless sensor modules	Yes	Yes	COTS solution which seems to do what we want. New (more integrated) version of GW module due out in April 2010.
Radiocrafts / Wavecom	M-Bus / ZigBee enabled integrated GSM / GPRS / EDGE GW module	Yes	No	New product. Seems to do what we want.
Testech	Embedded GW modules (ZigBee / WiFi to GSM / GPRS) + integrated sensors (inc. accelerometers)	Yes – or custom-built modules to customer specifications.	No	COTS devices available, but Testech specialize in doing custom solutions for particular customer requirements. Could do GW module + assist with sensor modules.
Arira Design / Savi / STMicro	DASH7 STM32 RFID HDK base board as system GW (and sensor module?)	No - development kit only	No	STM32 RFID HDK base board is available as a development board. Can include integrated sensors (but separate sensor modules not available?)
Arch Rock	IPsensor Node + Arch Rock IP-based wireless mesh network	Yes	?	Web-based system rather than GSM/GPRS. Anecdotally, it is quite difficult to get set up. Also requires expensive kit at the GW module.
WirelessLogic	For GW to Control Centre end, provide solutions for secure, fixed-IP routing	Yes	Yes	Technology suitable for the gateway to control centre end of the system.
Micro-Technic	SBC-2800 module with integrated GSM / GPRS modem (no intermediate gateway)	Yes		Single-board computer module with integrated GSM / GPRS and various I/O options (for sensors, etc.) An alternative to the Apoideas solution. Same questions about connection speed may apply.
Beanair	BeanGateway	Yes	No	

Supplier	System	COTS?	UK Base?	Notes
Low Power Radio Solutions	Various proprietary short- and long-range radio modules and modems	Yes	Yes	
Telegesis	Primarily ZigBee modules	Yes		Links with various suppliers involved in smart metering applications
Adaptive Modules	Distributors of a wide range of wireless modules. WiMetry cellular comms concentrator: ZigBee – 3G / GPRS connectivity. Have also developed µ-weave gateway system with Amscreen and Comtech.	Yes	Yes	Amscreen / Comtech (Lancashire): µWEAVE Gateway - Intelligent GSM/GPRS gateway enabling the remote machine to communicate reliably with µWEAVE software via the GSM/GPRS network and the Internet. It offers data logging, alarm processing, scheduling, configuration and robust communication.
Wireless Logic	M2M aggregator of data SIMs, and provider of secure fixed –IP connectivity over private APN using 3G and GPRS	Yes	Yes	Links with Sequoia (supplier of various wireless modules / GPRS modems).
Laird Technologies	Various wireless modules including soon-to-be-released "Access Point Gateway" product	Yes	Yes	Access Point Gateway – release mid-2010: embedded Linux OS with open source Lua scripting language for user-defined operation. Initially incorporating Bluetooth wireless link to GSM / GPRS.
Jennic	Various wireless modules and kits Development kits available for e.g. intelligent lighting system	Yes		Applications include smart metering and intelligent lighting systems including 2.4 GHz wireless – GPRS gateway-based systems
Telit	Loads of M2M / wireless stuff, including cellular GSM / GPRS modules	Yes		Various relevant applications of Telit components in customers systems – e.g. smart metering

Table 4 : Summary of Potential Gateway Module Suppliers

9. APPENDIX 4: DETAILED POWER ANALYSIS OF PRIMARY SAFETY SYSTEM SENSING MODULES

An approximate power calculation can be carried out for the components and operations proposed for the primary safety system sensing modules.

9.1 ENVIRONMENTAL SENSING MODULE

Temperature Sensor: LM60

The LM60 is able to operate at a supply voltage of 3 V with an operating current of 110 µA. If it is assumed that the sensor is energized for 1 second every 5 minutes (for example, at a sampling rate of 100 samples per second, this would give 100 readings from which an average temperature reading could be obtained), then the average current is ~ 0.37 µA and the average power consumption 1.1 µW.

Note that in practice a periodicity of 5 minutes is probably much shorter than required unless a hazardous environmental situation is actually present or imminent: if the temperature is well away from 0 ℃ then there is probably no need to sample so frequently, and hence the average power consumption will be correspondingly less.

Leaf Wetness Sensor: Decagon LWS

At an operating voltage of 3 V the Decagon LWS draws approximately 3 mA of current. Again assuming a 1 second excitation every 5 minutes, the average current is 10 µA and the average power consumption 30 µW.

Radio Module: Ezurio BISMS02BI-01 Embedded Intelligent Bluetooth Serial Module

The aim is to have the radio module unpowered unless it is actually being used to send or receive messages. In effect therefore, the radio module is either using no power, or it is using power based on its maximum current draw of ~ 36 mA at 3.3 V – 118.8 mW. The messages which need to be sent or received are described in Table 5,**¡Error! No se encuentra el origen de la referencia.** below (based on the data given in Table 1 of Smart RRS document D5.2 – Tertiary System Architecture, but with the status and time synch update period extended from 1 hour to 1 day).

Message	Message Size (Bytes)	Frequency	No. Sensors per Gateway	Notes
Environmental Risk	16	12 / hr (max.)	5 (1 for demo)	Message from environmental sensing module to the GW module when an environmental risk occurs, confidence level changes or disappears.
Environmental sensor status	17	1 / day	5 (1 for demo)	Message from environmental sensing module to the GW module transmitted daily (on receipt of Time Sync message) indicating the status of the environmental sensing module.
Environmental sensor time sync	14	1 / day	5 (1 for demo)	Message from GW module to the environmental sensing module transmitted daily resetting the internal clocks of the sensing modules. It's not entirely clear how the latency of the transmission and reception of this message can be accounted for.

Table 5 : Messages for Environmental Sensing Module

For the actual "Environmental Risk" message, a frequency of 12 / hr (once every 5 minutes) is indicated in Table 5: this is considered to be the maximum that is likely to be required, and for much of the time, it is likely to be much less than this. However, assuming this maximum rate, the module is required to transmit 12 x 16 x 8 = 1536 bits of data every hour. In principle the Bluetooth 2.0 radio can transmit at a maximum rate of 3 Mbits per second: however, experience shows that the maximum rate is never achieved in practice, so a rate of half this value – 1.5 Mbits per second – may be more realistic. At this rate of data transfer the radio can transmit the 1536 bits of data in a little over a millisecond: in principle, therefore, the radio only needs to be powered for about 1 ms in every hour, even at the maximum message rate of 12 messages per hour. In this case, the average power used by the radio is approximately 33.8 µW. In practice, it won't be possible to power the radio, instantly transmit the message, and then power down again: there will be some additional latency involved in this process. However, this will be offset to some extent by the fact that the 12 messages / hr rate will not be required in general: for much of the time, no messages at all will be required to be transmitted.

For the incoming "Sensor Time Synch" and outgoing "Sensor Status" messages, the situation is complicated by the current uncertainty over precisely how the time synch update is going to be achieved. If the radio normally off, it needs to be "woken up" in order to transmit and receive these messages. One option is to use a clock on the processor board to time the waking up of the radio (once per day): the environmental sensor module transmits its status message (8 x 17 = 136 bits) and receives the time synch message from the GW module (8 x 14 = 112 bits), and then shuts down again. In this way, the radio is only powered for a minimal amount of time (248 bits @ 1.5 Mbits per second = 0.17 ms per day: average power consumption ~ 0.23 µW: again, in reality, there will be additional latency involved).

Based on these assumptions and approximations, therefore, the average power consumption of the radio sub-system of the environmental sensing module is ~ 34 µW.

Microprocessor TI MSP430

Computing average power consumption for the microprocessor is not straightforward. Although the main operations it needs to perform are known (see above), the precise amount of time the device might require to perform any given algorithm isn't known. However, an estimate may be made using data supplied by TI[6]. This document indicates that, for the example of the MSP430F26xx family of microprocessors operating at 3 V, the average current operating in low-power mode is ~ 0.6 µA, whereas when operating in active mode (1 MIPS), the average current is ~ 515 µA.

The same paper indicates that, for most applications, the processor typically spends between 0.1% and 1% of its time in active mode and the rest in standby mode, 0.1 % active being typical for a wireless sensor device such as the Smart RRS environmental sensor module. These figures respectively correspond to 14.4 minutes and 1.4 minutes of active time / day (1.4 minutes of active time / day is equivalent, for example, to 4k active cycles every 4 seconds at 1MHz CPU clock rate). Based on these values, the average current drawn by the microprocessor is therefore typically between 1.11 µA and 5.74 µA, and the corresponding average power consumption (at 3 V supply) between 3.3 µW (for a typical wireless sensor module) and 17.2 µW.

Total Power Consumed and Battery Life-time

Summing all these contributions together, the total average power consumption for the Smart RRS environmental sensing module for the mode of operation specified is 1.1 + 30 + 34 + 3.3 = 68.4 µW.

The total average current is 0.37 + 10 + 10.3 + 1.11 = 21.78 µA. Assuming a battery capacity of 2000 mA.hr, the total expected life-time is given by:

Life-time = 2000 / 0.02178 = 91827.4 hrs, or ~ 10.5 years.

A larger battery capacity will obviously give a longer life-time, and should ensure that a sufficiently long life-time is achievable even if the approximate figures used in the calculations above are a factor of a few in error.

[6] Z. Albus, A. Valenzuela and M. Buccini: "Ultra-low Power Comparison: MSP430 vs Microchip XLP Tech. Brief"; Texas Instruments, October 2009.