

SearchWing RFD868+ Modem Boot Problem Analysis

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Problem Description

The RFD868+ modems sometimes show a very high packet error rate of 80 to 90% after boot. This state can only be left via a new cold boot. This happens in maybe 1 out of 10 cold boots. Bug tracking is here:

<https://gitlab.com/searchwing/development/drone-electronics/-/issues/1>

<https://discuss.ardupilot.org/t/rfd868-modems-stuck-after-boot-although-green-leds-are-both-on/96835/3>

Test Setup

I use the python test environment from Tridges SiK Firmware Repository. The SiK repository is available on github.

Hardware Setup

I use a MacBook Pro Early 2015 running MacOS 12.6.3 Monterey with two RFD868+ modems. The modems are attached via FTDI cables to two usb ports of the laptop. The modems appear as

```
ls /dev/tty.usbserial-*  
/dev/tty.usbserial-A6021FT5  
/dev/tty.usbserial-AQ004M71
```

in the device tree.

Modem firmware version and parameter setup

The RFD868+ modems use the factory firmware and parameter setup. The firmware version is 1.9. That is the factory firmware version. The modem parameters can be retrieved via the AT mode of the modem:

```
ATI0  
RFD SiK 1.9 on RFD900P  
ATI5  
S0:FORMAT=26  
S1:SERIAL_SPEED=57  
S2:AIR_SPEED=64  
S3:NETID=25  
S4:TXPOWER=20  
S5:ECC=0  
S6:MAVLINK=1  
S7:OPPRESEND=0  
S8:MIN_FREQ=868000  
S9:MAX_FREQ=869000  
S10:NUM_CHANNELS=10  
S11:DUTY_CYCLE=100  
S12:LBT_RSSI=0  
S13:MANCHESTER=0  
S14:RTSCTS=0  
S15:MAX_WINDOW=131  
S16:ENCRYPTION_LEVEL=0
```

Download the Firmware and Tools repository:

```
cd searchwing
git clone https://github.com/ArduPilot/SiK
```

Install the python mavproxy environment in a virtual environment

```
python3 -m venv venv
source venv/bin/activate
python -m pip install future lxml pymavlink MAVProxy pexpect geocoder flake8
empy
```

Run tests

I use the mavtester.py test which comes with the SiK repository

```
cd searchwing/SiK/Firmware/tools
./mavtester.py --port1=/dev/tty.usbserial-A6021FT5 --port2=/dev/tty.usbserial-
AQ004M71 --rate=3
```

The test emulates the mavlink communication between a ground station and a vehicle. The transmission packet rate of the mavtester.py test can be adapted. With the default rate I see packet loss already with a working modem setup. This is probably due to the 57600 baud serial speed link which can only messages at a certain rate. I reduced the rate parameter to 3 such that I see no packet loss under „good“ conditions.

Test results

When the connection is „good“, then I see the following test log

```
(venv) Fredo-2:tools fritz$ ./mavtester.py --port1=/dev/tty.usbserial-AQ004M71
--port2=/dev/tty.usbserial-A6021FT5 --rate=3
Draining ports
Starting threads
Veh:34/4/0 GCS:2/30/30 pend:4 rates:43/1000 lat:0/0/0 bad:0/0 txbuf:67/100
rssi:216/0 noise:54/0 loss:0:0%/0:0% fixed:0/0
Veh:85/12/2 GCS:4/83/81 pend:4 rates:43/1500 lat:137/137/137 bad:0/0
txbuf:70/100 rssi:217/217 noise:47/53 loss:0:0%/0:0% fixed:0/0
Veh:136/20/4 GCS:6/140/136 pend:0 rates:43/1500 lat:137/155/146 bad:0/0
txbuf:86/100 rssi:217/217 noise:52/52 loss:0:0%/0:0% fixed:0/0
Veh:187/28/6 GCS:8/192/186 pend:1 rates:43/1500 lat:91/155/127 bad:0/0
txbuf:67/100 rssi:217/217 noise:51/49 loss:0:0%/0:0% fixed:0/0
Veh:238/36/8 GCS:10/242/234 pend:4 rates:43/1500 lat:91/155/129 bad:0/0
txbuf:70/100 rssi:217/217 noise:48/53 loss:0:0%/0:0% fixed:0/0
Veh:289/44/10 GCS:12/299/289 pend:0 rates:43/1500 lat:91/155/124 bad:0/0
txbuf:92/100 rssi:217/217 noise:54/52 loss:0:0%/0:0% fixed:0/0
Veh:340/52/12 GCS:14/352/340 pend:0 rates:43/1500 lat:82/155/117 bad:0/0
txbuf:72/100 rssi:217/217 noise:53/50 loss:0:0%/0:0% fixed:0/0
Veh:391/60/14 GCS:16/400/386 pend:5 rates:43/1500 lat:82/155/121 bad:0/0
txbuf:70/100 rssi:217/217 noise:51/54 loss:0:0%/0:0% fixed:0/0
Veh:442/68/16 GCS:18/456/440 pend:2 rates:43/1500 lat:82/155/123 bad:0/0
txbuf:92/100 rssi:217/217 noise:52/49 loss:0:0%/0:0% fixed:0/0
Veh:493/76/18 GCS:20/511/493 pend:0 rates:43/1500 lat:57/155/116 bad:0/0
txbuf:82/100 rssi:217/217 noise:47/53 loss:0:0%/0:0% fixed:0/0
Veh:544/84/20 GCS:22/559/539 pend:5 rates:43/1500 lat:57/155/116 bad:0/0
txbuf:70/100 rssi:217/217 noise:50/49 loss:0:0%/0:0% fixed:0/0
Veh:595/92/22 GCS:24/613/591 pend:4 rates:43/1500 lat:57/155/117 bad:0/0
txbuf:67/100 rssi:217/217 noise:49/51 loss:0:0%/0:0% fixed:0/0
Veh:646/100/24 GCS:26/670/646 pend:0 rates:43/1500 lat:57/205/124 bad:0/0
txbuf:89/100 rssi:217/217 noise:53/50 loss:0:0%/0:0% fixed:0/0
Veh:697/108/26 GCS:28/722/696 pend:1 rates:43/1500 lat:57/205/125 bad:0/0
txbuf:74/100 rssi:217/217 noise:50/52 loss:0:0%/0:0% fixed:0/0
```

```

Veh:748/116/28 GCS:30/774/746 pend:2 rates:43/1500 lat:57/205/124 bad:0/0
txbuf:70/100 rssi:217/217 noise:50/49 loss:0:0%/0:0% fixed:0/0
Veh:799/124/30 GCS:32/829/799 pend:0 rates:43/1500 lat:57/205/128 bad:0/0
txbuf:93/100 rssi:217/217 noise:50/56 loss:0:0%/0:0% fixed:0/0
Veh:850/132/32 GCS:34/882/850 pend:0 rates:43/1500 lat:57/205/130 bad:0/0
txbuf:81/100 rssi:217/217 noise:49/53 loss:0:0%/0:0% fixed:0/0
Veh:901/140/34 GCS:36/935/901 pend:0 rates:43/1500 lat:57/205/129 bad:0/0
txbuf:70/100 rssi:217/217 noise:52/50 loss:0:0%/0:0% fixed:0/0
Veh:952/148/36 GCS:38/983/947 pend:5 rates:43/1500 lat:57/231/134 bad:0/0
txbuf:70/100 rssi:217/217 noise:50/54 loss:0:0%/0:0% fixed:0/0
Veh:1003/156/38 GCS:40/1041/1003 pend:0 rates:43/1500 lat:57/231/135 bad:0/0
txbuf:86/100 rssi:217/217 noise:50/50 loss:0:0%/0:0% fixed:0/0
Veh:1054/164/40 GCS:42/1094/1054 pend:0 rates:43/1500 lat:57/231/133 bad:0/0
txbuf:70/100 rssi:217/217 noise:55/49 loss:0:0%/0:0% fixed:0/0
Veh:1105/172/42 GCS:44/1143/1101 pend:4 rates:43/1500 lat:57/231/137 bad:0/0
txbuf:70/100 rssi:217/217 noise:48/49 loss:0:0%/0:0% fixed:0/0
Veh:1156/180/44 GCS:46/1200/1156 pend:0 rates:43/1500 lat:57/231/136 bad:0/0
txbuf:92/100 rssi:217/217 noise:50/47 loss:0:0%/0:0% fixed:0/0
Veh:1207/188/46 GCS:48/1253/1207 pend:0 rates:43/1500 lat:57/231/135 bad:0/0
txbuf:75/100 rssi:217/217 noise:56/47 loss:0:0%/0:0% fixed:0/0
Veh:1258/196/48 GCS:50/1302/1254 pend:4 rates:43/1500 lat:57/239/139 bad:0/0
txbuf:70/100 rssi:217/217 noise:50/49 loss:0:0%/0:0% fixed:0/0
Veh:1309/204/50 GCS:52/1357/1307 pend:2 rates:43/1500 lat:57/239/139 bad:0/0
txbuf:70/100 rssi:217/217 noise:52/51 loss:0:0%/0:0% fixed:0/0
Veh:1360/212/52 GCS:54/1412/1360 pend:0 rates:43/1500 lat:44/239/135 bad:0/0
txbuf:79/100 rssi:217/217 noise:55/48 loss:0:0%/0:0% fixed:0/0
Veh:1411/220/54 GCS:56/1462/1408 pend:3 rates:43/1500 lat:44/239/134 bad:0/0
txbuf:70/100 rssi:217/217 noise:52/53 loss:0:0%/0:0% fixed:0/0
Veh:1462/228/56 GCS:58/1514/1458 pend:4 rates:43/1500 lat:44/239/134 bad:0/0
txbuf:67/100 rssi:217/217 noise:50/47 loss:0:0%/0:0% fixed:0/0
Veh:1513/236/58 GCS:60/1571/1513 pend:0 rates:43/1500 lat:44/239/134 bad:0/0
txbuf:87/100 rssi:217/217 noise:50/51 loss:0:0%/0:0% fixed:0/0
Veh:1564/244/60 GCS:62/1623/1563 pend:1 rates:43/1500 lat:44/239/134 bad:0/0
txbuf:73/100 rssi:217/217 noise:50/52 loss:0:0%/0:0% fixed:0/0
Veh:1615/252/62 GCS:64/1673/1611 pend:4 rates:43/1500 lat:44/239/134 bad:0/0
txbuf:67/100 rssi:217/217 noise:50/48 loss:0:0%/0:0% fixed:0/0
Veh:1666/260/64 GCS:66/1730/1666 pend:0 rates:43/1500 lat:44/239/134 bad:0/0
txbuf:92/100 rssi:217/217 noise:52/49 loss:0:0%/0:0% fixed:0/0
Veh:1717/268/66 GCS:68/1783/1717 pend:0 rates:43/1500 lat:44/239/135 bad:0/0
txbuf:79/100 rssi:217/217 noise:53/52 loss:0:0%/0:0% fixed:0/0

```

The meaning of a log line like this

```
Veh:1717/268/66 GCS:68/1783/1717
```

is Type:transmitted messages/received messages/received messages without RADIO messages. So the „Vehicle“ has transmitted 1717 messages, received 268 messages in total and 66 „real“ messages. The groundstation has transmitted 68 packets, received 1783 messages and 1717 without RADIO messages. So this line shows that the 1717 transmitted packets from vehicle have all been received by the ground station. Everything is o.k. The loss item shows zero lost packets and a packet loss rate of zero percent.

In approximately 1 out of 10 cold boots, the log looks like this:

```

(venv) Fredo-2:tools fritz$ ./mavtester.py --port1=/dev/tty.usbserial-AQ004M71
--port2=/dev/tty.usbserial-A6021FT5 --rate=3
Draining ports
Starting threads
Veh:34/4/0 GCS:2/7/7 pend:27 rates:43/1000 lat:0/0/0 bad:0/0 txbuf:64/100
rssi:206/0 noise:49/0 loss:0:0%/0:0% fixed:0/0

```

Veh:85/10/0 GCS:4/9/7 pend:78 rates:43/1500 lat:0/0/0 bad:0/0 txbuf:58/100
rssi:206/184 noise:46/50 loss:0:0%/0:0% fixed:0/0
Veh:136/16/0 GCS:6/12/8 pend:128 rates:43/1500 lat:0/0/0 bad:0/0 txbuf:96/100
rssi:206/177 noise:50/48 loss:105:92%/0:0% fixed:0/0
Veh:187/22/0 GCS:8/19/13 pend:174 rates:43/1500 lat:0/0/0 bad:0/0 txbuf:82/100
rssi:207/180 noise:49/53 loss:162:92%/0:0% fixed:0/0
Lost 11 GLOBAL_POSITION_INT messages
Veh:238/28/0 GCS:10/28/20 pend:218 rates:43/1500 lat:0/0/0 bad:0/0
txbuf:70/100 rssi:191/190 noise:49/49 loss:167:89%/0:0% fixed:0/0
Veh:289/34/0 GCS:12/37/27 pend:262 rates:43/1500 lat:0/0/0 bad:0/0
txbuf:52/100 rssi:197/196 noise:48/51 loss:216:88%/0:0% fixed:0/0
Lost 6 GLOBAL_POSITION_INT messages
Veh:340/40/0 GCS:14/46/34 pend:306 rates:43/1500 lat:0/0/0 bad:0/0
txbuf:64/100 rssi:198/199 noise:49/51 loss:272:88%/0:0% fixed:0/0
Veh:391/46/0 GCS:16/51/37 pend:354 rates:43/1500 lat:0/0/0 bad:0/0
txbuf:70/100 rssi:202/199 noise:49/50 loss:330:89%/0:0% fixed:0/0
Veh:442/54/2 GCS:18/53/37 pend:405 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:52/100 rssi:202/200 noise:50/50 loss:330:89%/0:0% fixed:0/0
Veh:493/60/2 GCS:20/55/37 pend:456 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:68/100 rssi:191/202 noise:49/50 loss:330:89%/0:0% fixed:0/0
Veh:544/66/2 GCS:22/57/37 pend:507 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:70/100 rssi:195/202 noise:51/50 loss:330:89%/0:0% fixed:0/0
Lost 13 GLOBAL_POSITION_INT messages
Veh:595/72/2 GCS:24/67/45 pend:550 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:64/100 rssi:196/199 noise:54/50 loss:497:91%/0:0% fixed:0/0
Lost 2 GLOBAL_POSITION_INT messages
Veh:646/78/2 GCS:26/84/60 pend:586 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:95/100 rssi:128/199 noise:48/50 loss:538:89%/0:0% fixed:0/0
Veh:697/84/2 GCS:28/86/60 pend:637 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:96/100 rssi:118/200 noise:47/52 loss:538:89%/0:0% fixed:0/0
Lost 6 GLOBAL_POSITION_INT messages
Veh:748/90/2 GCS:30/95/67 pend:681 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:64/100 rssi:131/202 noise:52/48 loss:647:90%/0:0% fixed:0/0
Veh:799/96/2 GCS:32/105/75 pend:724 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:70/100 rssi:144/203 noise:48/50 loss:699:90%/0:0% fixed:0/0
Veh:850/102/2 GCS:34/113/81 pend:769 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:70/96 rssi:171/203 noise:45/51 loss:745:90%/0:0% fixed:0/0
Veh:901/108/2 GCS:36/115/81 pend:820 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:64/100 rssi:188/204 noise:48/51 loss:745:90%/0:0% fixed:0/0
Veh:952/114/2 GCS:38/124/88 pend:864 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:70/100 rssi:197/203 noise:45/46 loss:801:90%/0:0% fixed:0/0
Veh:1003/120/2 GCS:40/126/88 pend:915 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:58/100 rssi:202/203 noise:48/57 loss:801:90%/0:0% fixed:0/0
Lost 16 GLOBAL_POSITION_INT messages
Veh:1054/126/2 GCS:42/144/104 pend:950 rates:43/1500 lat:227/227/227 bad:0/0
txbuf:57/100 rssi:205/205 noise:44/50 loss:910:89%/0:0% fixed:0/0
Veh:1105/134/4 GCS:44/146/104 pend:1001 rates:43/1500 lat:120/227/173 bad:0/0
txbuf:58/100 rssi:211/214 noise:48/52 loss:910:89%/24:85% fixed:0/0
Veh:1156/142/6 GCS:46/155/111 pend:1045 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:58/100 rssi:214/183 noise:49/52 loss:1016:90%/24:80% fixed:0/0
Veh:1207/148/6 GCS:48/171/125 pend:1082 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:64/100 rssi:216/195 noise:48/52 loss:1070:89%/24:80% fixed:0/0
Lost 13 GLOBAL_POSITION_INT messages
Veh:1258/154/6 GCS:50/181/133 pend:1125 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:58/100 rssi:196/205 noise:43/51 loss:1104:89%/24:80% fixed:0/0
Veh:1309/160/6 GCS:52/183/133 pend:1176 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:70/100 rssi:168/210 noise:46/49 loss:1104:89%/24:80% fixed:0/0
Veh:1360/166/6 GCS:54/192/140 pend:1220 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:64/100 rssi:159/213 noise:44/48 loss:1159:89%/24:80% fixed:0/0
Veh:1411/172/6 GCS:56/194/140 pend:1271 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:70/100 rssi:144/215 noise:48/46 loss:1159:89%/24:80% fixed:0/0
Veh:1462/178/6 GCS:58/201/145 pend:1317 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:64/100 rssi:161/218 noise:46/49 loss:1276:89%/24:80% fixed:0/0
Lost 13 GLOBAL_POSITION_INT messages

Veh:1513/184/6 GCS:60/211/153 pend:1360 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:65/100 rssi:168/218 noise:49/48 loss:1326:89%/24:80% fixed:0/0
Veh:1564/190/6 GCS:62/213/153 pend:1411 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:70/100 rssi:191/218 noise:47/49 loss:1326:89%/24:80% fixed:0/0
Lost 5 GLOBAL_POSITION_INT messages
Veh:1615/196/6 GCS:64/222/160 pend:1455 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:70/100 rssi:207/202 noise:47/51 loss:1416:89%/24:80% fixed:0/0
Veh:1666/202/6 GCS:66/236/172 pend:1494 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:89/100 rssi:211/194 noise:44/51 loss:1486:89%/24:80% fixed:0/0
Veh:1717/208/6 GCS:68/239/173 pend:1544 rates:43/1500 lat:120/246/197 bad:0/0
txbuf:58/100 rssi:212/195 noise:46/49 loss:1486:89%/24:80% fixed:0/0
Veh:1768/216/8 GCS:70/241/173 pend:1595 rates:43/1500 lat:120/246/185 bad:0/0
txbuf:70/100 rssi:215/203 noise:44/50 loss:1486:89%/46:85% fixed:0/0
Veh:1819/222/8 GCS:72/249/179 pend:1640 rates:43/1500 lat:120/246/185 bad:0/0
txbuf:78/100 rssi:172/164 noise:46/50 loss:1599:89%/46:85% fixed:0/0
Veh:1870/228/8 GCS:74/251/179 pend:1691 rates:43/1500 lat:120/246/185 bad:0/0
txbuf:58/96 rssi:192/183 noise:45/55 loss:1599:89%/46:85% fixed:0/0
Lost 17 GLOBAL_POSITION_INT messages
Veh:1921/234/8 GCS:76/260/186 pend:1735 rates:43/1500 lat:120/246/185 bad:0/0
txbuf:64/100 rssi:201/195 noise:51/54 loss:1701:90%/46:85% fixed:0/0
Veh:1972/240/8 GCS:78/262/186 pend:1786 rates:43/1500 lat:120/246/185 bad:0/0
txbuf:84/100 rssi:205/201 noise:50/48 loss:1701:90%/46:85% fixed:0/0
Veh:2023/248/10 GCS:80/271/193 pend:1830 rates:43/1500 lat:120/257/199 bad:0/0
txbuf:58/100 rssi:207/202 noise:49/50 loss:1816:90%/54:84% fixed:0/0
Veh:2074/254/10 GCS:82/273/193 pend:1881 rates:43/1500 lat:120/257/199 bad:0/0
txbuf:57/100 rssi:214/204 noise:47/51 loss:1816:90%/54:84% fixed:0/0
Veh:2125/260/10 GCS:84/275/193 pend:1932 rates:43/1500 lat:120/257/199 bad:0/0
txbuf:58/100 rssi:194/177 noise:50/47 loss:1816:90%/54:84% fixed:0/0
Veh:2176/266/10 GCS:86/293/209 pend:1967 rates:43/1500 lat:120/257/199 bad:0/0
txbuf:71/100 rssi:200/193 noise:46/53 loss:1925:90%/54:84% fixed:0/0

Looking at the last line

Veh:2176/266/10 GCS:86/293/209 pend:1967 rates:43/1500 lat:120/257/199 bad:0/0
txbuf:71/100 rssi:200/193 noise:46/53 loss:1925:90%/54:84% fixed:0/0

the vehicle has transmitted 2176 messages but only 209 have been received by the ground station. The reported packet loss rates are 90% and 84%.

Analysis

Thomas from RF Design figured out that there might be a problem with our Modem setup. This modem setup is the default factory setup for our RFD868+ modems.

```
ATI0
RFD SiK 1.9 on RFD900P
ATI5
S0:FORMAT=26
S1:SERIAL_SPEED=57
S2:AIR_SPEED=64
S3:NETID=25
S4:TXPOWER=20
S5:ECC=0
S6:MAVLINK=1
S7:OPPRESEND=0
S8:MIN_FREQ=868000
S9:MAX_FREQ=869000
S10:NUM_CHANNELS=10
S11:DUTY_CYCLE=100
S12:LBT_RSSI=0
S13:MANCHESTER=0
S14:RTSCTS=0
S15:MAX_WINDOW=131
```

S16: ENCRYPTION_LEVEL=0

RFDDesign has a propriety firmware. This firmware has been developed in cooperation with [Tridge](#) who provides an open source firmware for the RFD868+ (and other) modems which use the SiLabs 1020-1060 silicon. The firmware is available on Github:

<https://github.com/ArduPilot/SiK>

I guess the propriety and the open source firmware behave at least similar to draw some conclusions.

The minimum frequency (8:MIN_FREQ=868000) is set to 868 MHz and the maximum frequency (S9:MAX_FREQ=869000) is set to 869 MHz which results in a usable bandwidth of 1 MHz. At the same time the number of frequency hopping channels (S10:NUM_CHANNELS=10) is set to 10. The RFD868+ modem uses a frequency hopping scheme where the transmitter and receiver channels switch the carrier frequency in a predefined manner that is derived from the NETID and the number of channels.

Looking at: <https://github.com/ArduPilot/SiK/blob/master/Firmware/radio/main.c#L403>

the channel spacing is computed by dividing the available bandwidth by 2 + number of channels. In our case that is 1 MHz / (2 + 10) = **83.3 kHz**. The first carrier frequency is located half the channel spacing above the minimum frequency. This obviously assumes that the required channel bandwidth for transmission is equal or lower than the channel spacing. In our case we have the following set of carrier frequencies ignoring some NETID based offset:

868041,66; 868125; 868208,33 ... 868625; 868708,33; 868791,66 kHz

Thomas from RFDDesign mentioned that the required bandwidth for transmitting at 64kBit/s data rate is around 250 kHz. In Tridges SiK Code, the programmed frequency deviation is

$fd = 63,75 \text{ kHz}$

f_s is the symbolrate which is for 64 kBits/s datarate and 2 level Gaussian Frequency Shift Keying 64 kHz. According to Carsons Rule, the required bandwidth is

$BW = 2 * fd + f_s = 2 * 63,75 \text{ kHz} + 64 \text{ kHz} = 191,5 \text{ kHz}$

In Tridges SiK firmware the programmed bandwidth of the IF filter for receive is 210 kHz which fits to the TX bandwidth. We therefore have an overlap between the channels. The SiLabs 102x/3x datasheet [2] shows in Figure 32.5 the behaviour of the Automatic Frequency Control (AFC). The purpose of the AFC is to handle frequency differences between the transmitter and the receiver as the quartz oszillators are not ideal. A typical quartz oszillator has a maximum frequency deviation of around 100ppm. For 865 MHz this would translate to 86.5 kHz quartz frequency offset error.

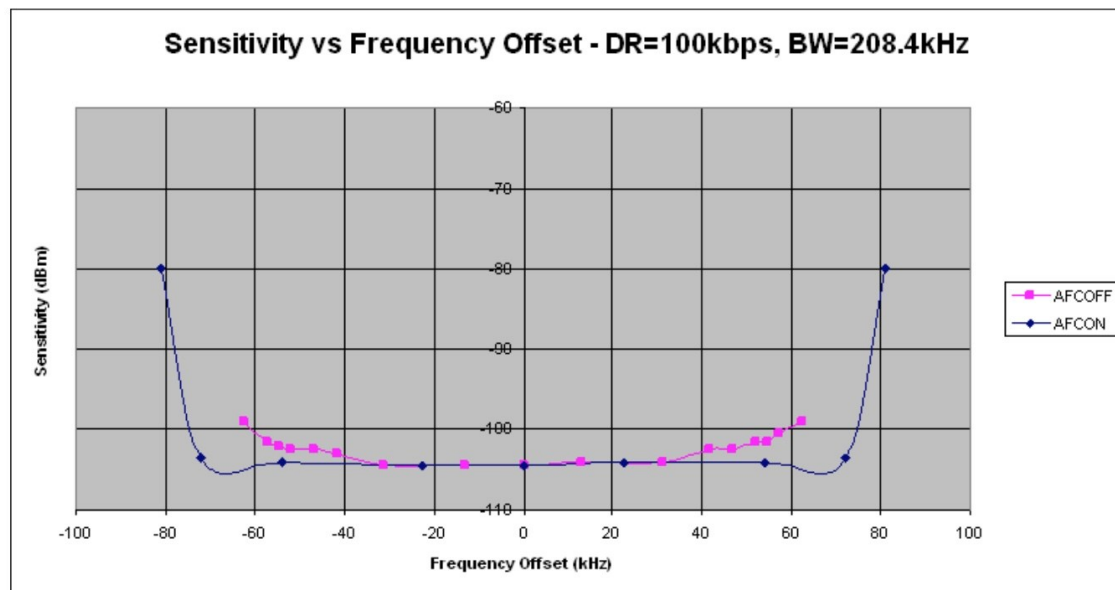


Figure 32.5. Sensitivity at 1% PER vs. Carrier Frequency Offset

The SiLab datasheet states that the AFC can compensate frequency deviations of around 0.25 – 0.35 of the IF bandwidth. The IF bandwidth programmed in the radio for a data rate of 64 kBit/s is 210 kHz. Therefore AFC could compensate 52 to 73 kHz of carrier offset.

The frequency hopping mechanism in the SiK firmware will stay for the MAX_WINDOW time in the channel and then hop to the next channel. MAX_WINDOW is configured to be 131 ms. The sequence of channels is derived from a pseudorandom sequence in a deterministic manner. The sequence depends on the NET_ID.

During synchronization the transmitter will transmit according to the hopping sequence, i.e. it will hop after each MAX_WINDOW. The receiver will hop only after the transmitter has hopped over all channels, i.e. the receiver changes the receive channel much slower than the transmitter. Once a packet has been successfully received, the receiver will hop with the nominal speed. So in sync state the receiver and transmitter hop to the same channel.

If one packet is received the receiver will leave the synchronization stage and enter the full communication.

Theory of the problem cause

My guess is that the channel spacing of 83 kHz is so close that the receiver can also receive packets if they are transmitted in a neighbor channel. Assume that the receiver listens on channel 7 at a center frequency of 868625 kHz. Assume that the transmitter starts transmitting on channel 8 at 868625 kHz + 83.3 kHz = 868708,3 kHz. If the receiver can receive a packet on channel 7 although the transmitter transmits on channel 8, then the receiver will switch to the sync state and start the hopping sequence.

Assume that the channel hop sequence for the ten channels is 7,3,5,1,9,0,2,8,6,4. If the receiver can receive a message in channel 7, although it was transmitted in channel 8, then the hop sequences will be out of sync:

TX: 8,6,4,7,3,5,1,9,0,2

RX: 7,3,5,1,9,0,2,8,6,4

When the receiver is in channel 3, the transmitter will transmit in 6. When the receiver is in channel 7,5,2 or 8, then the transmitter is in a neighbor channel where there is a certain chance that a packet might be received. For all other channels the frequencies are too far off. This will result in a massive packet loss.

Test with one channel and 3 MHz bandwidth

I changed the min and max frequency to 867 MHz and 870 MHz and the number of channels to 1.

```
ATI5
S0:FORMAT=26
S1:SERIAL_SPEED=57
S2:AIR_SPEED=64
S3:NETID=25
S4:TXPOWER=20
S5:ECC=0
S6:MAVLINK=1
S7:OPPRESEND=0
S8:MIN_FREQ=867000
S9:MAX_FREQ=870000
S10:NUM_CHANNELS=1
S11:DUTY_CYCLE=100
S12:LBT_RSSI=0
S13:MANCHESTER=0
S14:RTSCTS=0
S15:MAX_WINDOW=131
S16:ENCRYPTION_LEVEL=0
```

With this test I could not reproduce the problem. Unplugging and Replugging modems did never end in the packet loss scenario.

Test with 10 channels and 5 MHz bandwidth

Philipp tested with modems in Berlin with 10 channels and 5 MHz bandwidth. Philipp used the following configuration:

```
S0:FORMAT=26
S1:SERIAL_SPEED=57
S2:AIR_SPEED=64
S3:NETID=25
S4:TXPOWER=20
S5:ECC=0
S6:MAVLINK=1
S7:OPPRESEND=0
S8:MIN_FREQ=865000
S9:MAX_FREQ=870000
S10:NUM_CHANNELS=10
S11:DUTY_CYCLE=100
S12:LBT_RSSI=0
S13:MANCHESTER=0
S14:RTSCTS=1
S15:MAX_WINDOW=131
S16:ENCRYPTION_LEVEL=0
```

He could also not reproduce the problem.

Test with 1 channel and a frequency offset between the two modems.

I changed the min and max frequency by adding an offset of 80 kHz on one modem. The other modem was left unchanged. The parameters of the modified modem are:

```
(venv) Fredo-2:tools fritz$ ./atcommander.py --list-local /dev/tty.usbserial-AQ004M71
Entering command mode...
Querying local radio...
radio version: 1.9 board type: 2 board version: 130
Parameters:
S0:FORMAT=26
S1:SERIAL_SPEED=57
S2:AIR_SPEED=64
S3:NETID=25
S4:TXPOWER=20
S5:ECC=0
S6:MAVLINK=1
S7:OPPRESEND=0
S8:MIN_FREQ=867080          «----- Frequency offset
S9:MAX_FREQ=870080
S10:NUM_CHANNELS=1
S11:DUTY_CYCLE=100
S12:LBT_RSSI=0
S13:MANCHESTER=0
S14:RTSCTS=0
S15:MAX_WINDOW=131
S16:ENCRYPTION_LEVEL=0
```

With this setup both modems are nominally off by 80 kHz. The real frequency offset between the two modems depends on the frequency of the local oscillator differences. For this setup the green LEDs sometimes go into the blinking state indicating a loss of synchronization. A test run shows the following log:

```
(venv) Fredo-2:tools fritz$ ./mavtester.py --port1=/dev/tty.usbserial-A6021FT5 --port2=/dev/tty.usbserial-AQ004M71 --rate=3
Draining ports
Starting threads
Veh:51/4/0 GCS:2/5/5 pend:46 rates:43/1500 lat:0/0/0 bad:0/0
txbuf:70/100 rssi:205/0 noise:51/0 loss:24:82%/0:0% fixed:0/0
Lost 1 GLOBAL_POSITION_INT messages
Veh:119/12/0 GCS:4/36/34 pend:85 rates:43/2000 lat:0/0/0 bad:0/0
txbuf:62/100 rssi:206/183 noise:48/50 loss:60:63%/0:0% fixed:0/0
Lost 1 GLOBAL_POSITION_INT messages
Veh:187/18/0 GCS:6/60/56 pend:131 rates:43/2000 lat:0/0/0 bad:0/0
txbuf:64/100 rssi:206/197 noise:49/47 loss:110:66%/0:0% fixed:0/0
Lost 6 GLOBAL_POSITION_INT messages
Veh:255/28/2 GCS:8/77/71 pend:184 rates:43/2000 lat:151/151/151
bad:0/0 txbuf:52/100 rssi:207/201 noise:55/48 loss:152:68%/0:0%
fixed:0/0
Veh:323/36/2 GCS:10/93/85 pend:238 rates:43/2000 lat:151/151/151
bad:0/0 txbuf:70/100 rssi:192/205 noise:52/47 loss:211:71%/0:0%
fixed:0/0
Veh:391/44/2 GCS:12/95/85 pend:306 rates:43/2000 lat:151/151/151
bad:0/0 txbuf:76/100 rssi:199/205 noise:56/52 loss:211:71%/0:0%
fixed:0/0
Lost 9 GLOBAL_POSITION_INT messages
Lost 2 GLOBAL_POSITION_INT messages
```

Veh:459/52/2 GCS:14/117/105 pend:354 rates:43/2000 lat:151/151/151
bad:0/0 txbuf:70/100 rssi:201/206 noise:51/50 loss:343:76%/0:0%
fixed:0/0

Veh:527/62/4 GCS:16/130/116 pend:411 rates:43/2000 lat:96/151/123
bad:0/0 txbuf:70/100 rssi:204/206 noise:57/49 loss:393:77%/6:60%
fixed:0/0

Lost 6 GLOBAL_POSITION_INT messages

Veh:595/70/4 GCS:18/155/139 pend:456 rates:43/2000 lat:96/151/123
bad:0/0 txbuf:70/100 rssi:204/206 noise:50/53 loss:437:75%/6:60%
fixed:0/0

Veh:663/76/4 GCS:20/164/146 pend:517 rates:43/2000 lat:96/151/123
bad:0/0 txbuf:64/100 rssi:205/200 noise:54/49 loss:465:76%/6:60%
fixed:0/0

Lost 4 GLOBAL_POSITION_INT messages

Lost 3 GLOBAL_POSITION_INT messages

Veh:731/88/6 GCS:22/188/168 pend:563 rates:43/2000 lat:55/151/100
bad:0/0 txbuf:58/100 rssi:206/204 noise:51/53 loss:548:76%/10:62%
fixed:0/0

Veh:799/96/6 GCS:24/198/176 pend:623 rates:43/2000 lat:55/151/100
bad:0/0 txbuf:85/100 rssi:207/206 noise:55/57 loss:561:76%/10:62%
fixed:0/0

Veh:867/104/6 GCS:26/217/193 pend:674 rates:43/2000 lat:55/151/100
bad:0/0 txbuf:64/100 rssi:207/206 noise:52/51 loss:639:76%/10:62%
fixed:0/0

Lost 7 GLOBAL_POSITION_INT messages

Veh:935/114/8 GCS:28/241/215 pend:720 rates:43/2000 lat:31/151/83
bad:0/0 txbuf:64/100 rssi:207/206 noise:55/48 loss:676:75%/14:63%
fixed:0/0

Lost 2 GLOBAL_POSITION_INT messages

Veh:1003/122/10 GCS:30/257/229 pend:774 rates:43/2000 lat:31/187/104
bad:0/0 txbuf:67/100 rssi:207/206 noise:51/48 loss:719:75%/14:58%
fixed:0/0

Lost 3 GLOBAL_POSITION_INT messages

Lost 1 GLOBAL_POSITION_INT messages

Veh:1071/132/10 GCS:32/302/272 pend:799 rates:43/2000 lat:31/187/104
bad:0/0 txbuf:92/100 rssi:208/206 noise:55/51 loss:793:74%/14:58%
fixed:0/0

Veh:1139/140/10 GCS:34/310/278 pend:861 rates:43/2000 lat:31/187/104
bad:0/0 txbuf:78/100 rssi:208/206 noise:55/57 loss:826:74%/14:58%
fixed:0/0

Lost 7 GLOBAL_POSITION_INT messages

Veh:1207/148/12 GCS:36/337/303 pend:904 rates:43/2000 lat:31/187/110
bad:0/0 txbuf:70/100 rssi:208/206 noise:55/49 loss:876:74%/18:60%
fixed:0/0

Veh:1275/158/12 GCS:38/352/316 pend:959 rates:43/2000 lat:31/187/110
bad:0/0 txbuf:64/100 rssi:208/206 noise:55/46 loss:951:75%/18:60%
fixed:0/0

Lost 7 GLOBAL_POSITION_INT messages

Veh:1343/166/12 GCS:40/372/334 pend:1009 rates:43/2000 lat:31/187/110
bad:0/0 txbuf:52/100 rssi:208/194 noise:56/50 loss:992:74%/18:60%
fixed:0/0

Lost 2 GLOBAL_POSITION_INT messages

Veh:1411/174/14 GCS:42/395/355 pend:1056 rates:43/2000 lat:31/187/120
bad:0/0 txbuf:70/100 rssi:208/201 noise:57/54 loss:1028:74%/22:61%
fixed:0/0

Veh:1479/184/14 GCS:44/410/368 pend:1111 rates:43/2000 lat:31/187/120
bad:0/0 txbuf:70/100 rssi:208/205 noise:57/50 loss:1089:74%/22:61%
fixed:0/0
Lost 5 GLOBAL_POSITION_INT messages
Lost 1 GLOBAL_POSITION_INT messages

With a configured frequency offset of 80 kHz with one channel, i.e. no frequency hopping, the modems still receive packets but with a packet loss rate of 74%. Depending on the real frequency offsets of the local oszillators it is therefore shown that the modems can still receive with a nominal offset of 80 kHz. Therefore it is possible that the modem can receive in a neighbor channel if the neighbor channel is only 80 kHz away.

Recommended Setup

According to the modem configuration in Tridge SiK firmware

https://github.com/ArduPilot/SiK/blob/master/Firmware/radio/radio_443x.c#L710

the „EZRADIOPRO_IF_FILTER_BANDWIDTH = 0x1C“ register is configured depending on the selected AIR_SPEED. Consulting SiK Application Note AN440 [3], the resulting intermediate frequency filter bandwidth is:

AIR_SPEED	Register Value (0x1C)	dwn3_bypass	ndec_exp[2..0]	filset[3..0]	IF Bandwidth
64	0x9A	true	1	10	210 kHz
128	0x88	true	0	8	335 kHz

I conclude that a AIR_SPEED of 128 kBit/s requires a higher bandwidth in the channel.

The purpose of the frequency hopping is to spread the transmitted power over the available frequencies such that one transmitter does not occupy a specific channel completely. To avoid the the problem of non sychronized frequency hopping, the channel spacing must be larger than the used bandwidth for the transmission.

According to Bundesnetzagentur [4] and ETSI [1]the 868 MHz ISM band is in the range 862 MHz to 870 MHz with different maximum transmit powers, access techniques and maximum duty cycle.

Offshore Setup

The setup was tested by Philipp.

```
S0:FORMAT=26
S1:SERIAL_SPEED=57
S2:AIR_SPEED=64
S3:NETID=25
S4:TXPOWER=20
S5:ECC=0
S6:MAVLINK=1
S7:OPPRESEND=0
S8:MIN_FREQ=865000
S9:MAX_FREQ=870000
S10:NUM_CHANNELS=10
S11:DUTY_CYCLE=100
S12:LBT_RSSI=0
S13:MANCHESTER=0
S14:RTSCTS=0
S15:MAX_WINDOW=131
S16:ENCRYPTION_LEVEL=0
```

It works with a frequency range between 865 and 870 MHz giving a bandwidth of 5 MHz. The channel spacing according to the SiK Firmware will be 416 kHz for the 10 channels. This spacing is well above the bandwidth of 210 kHz for 64kBits/s. This channel spacing should also work for an air rate of 128 kBits/s. This setup is not compliant to EU regulations.

EU Setup High Power

The EU allows up to 500 mW ERP power in the band 869400 kHz to 869650 kHz with a duty cycle of 10%. Due to the duty cycle of 10%, the throughput will be reduced from nominal 64kBit/s to 6,4kBit/s. The bandwidth is only 250 kHz, i.e. there is only enough space for one 64kBits/s channel. Therefore the number of channels is set to 1.

```
(venv) Fredo-2:tools fritz$ ./atcommander.py --list-local --list-remote
/dev/tty.usbserial-AQ004M71
Entering command mode...
Querying local radio...
radio version: 1.9 board type: -1 board version: 4
Parameters:
S0:FORMAT=26
S1:SERIAL_SPEED=57
S2:AIR_SPEED=64
S3:NETID=25
S4:TXPOWER=20
S5:ECC=0
S6:MAVLINK=1
S7:OPPRESEND=0
S8:MIN_FREQ=869400
S9:MAX_FREQ=869650
S10:NUM_CHANNELS=1
S11:DUTY_CYCLE=10
S12:LBT_RSSI=0
S13:MANCHESTER=0
S14:RTSCTS=0
S15:MAX_WINDOW=131
S16:ENCRYPTION_LEVEL=0
```

```
Querying remote radio...
radio version: 1.9 board type: 2 board version: 130
```

Parameters:
S0:FORMAT=26
S1:SERIAL_SPEED=57
S2:AIR_SPEED=64
S3:NETID=25
S4:TXPOWER=20
S5:ECC=0
S6:MAVLINK=1
S7:OPPRESEND=0
S8:MIN_FREQ=869400
S9:MAX_FREQ=869650
S10:NUM_CHANNELS=1
S11:DUTY_CYCLE=10
S12:LBT_RSSI=0
S13:MANCHESTER=0
S14:RTSCTS=0
S15:MAX_WINDOW=131

I tested this setup with a reduced packet transmission rate of 1 successfully.

```
./mavtester.py --port1=/dev/tty.usbserial-A6021FT5 --port2=/dev/tty.usbserial-AQ004M71 -rate=1  
...  
Veh:357/80/40 GCS:42/380/340 pend:17 rates:43/500 lat:61/249/138 bad:0/0  
txbuf:77/100 rssi:219/222 noise:48/45 loss:0:0%/0:0% fixed:0/0
```

EU Setup Listen Before Talk (LBT_RSS)

The RFD868+ modem has a parameter LBT_RSSI which enables the listen before talk mode that is supposed to be compliant with the EU „polite spectrum access“. I could not set the parameter to something different than 0 (= disable) in the 1.9 firmware.

Literature

- [1] ETSI, [ETSI EN 300 220-2 V3.1.1 \(2017-02\)](#), 2017
- [2] Silicon Laboratories, [Silab Si 102x/3x datasheet](#), 2013
- [3] Silicon Laboratories, [AN440: Si4430/31/32 REGISTER DESCRIPTIONS](#), 2015
- [4] Bundesnetzagentur, [Verfügung 133/2019 - Allgemeinzuteilung von Frequenzen zur Nutzung durch Funkanwendungen geringer Reichweite \(SRD\)](#), 2019