Sage's Modem Protocol Analyzer

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1 Introduction

A large portion of home internet and email accesses are still through dial-up modem calls. Compared with voice calls, failed modem calls are far more annoying to the end users, especially when a modem call is disconnected prematurely in the middle of a file transfer. Unfortunately, as most users can attest, modem calls do fail more often than voice calls.

A modem call can fail for all sorts of reasons. The intention of Sage's Modem Protocol Analyzer (abbreviated as SMPA from here on) is to help identify the exact cause. SMPA is specifically designed to analyze the protocols of V.9x [4] (V.90, V.91 and V.92) and V.34 [3] modems. To internet service providers (ISP), such a tool can help improve customer satisfaction. To telephone operators, such a tool can be used to achieve higher call success rate. To modem manufacturers, this protocol analyzer can help improve modem compatibility and guarantee strict conformity to known standards. To certain enterprise or private users, such a tool can be used to find out what the modems are actually doing besides transferring application-layer data, and therefore figure out why sometimes the web browsers feel so sluggish.

SMPA is a real-time, passive and listening-only modem call monitoring tool. SMPA works by simultaneously monitoring and analyzing the signals from both modems, and displaying the relevant time-stamped information all in real-time. Test access is through DS1-level (T1 or E1) monitoring mode. Depending on platforms, a single SMPA can analyze one to many modem calls at the same time.

To understand all the messages from SMPA, one has to understand all the signals that are exchanged before the actual application-layer data transfer starts during a modem call. In the following sections, we will go through the signal sequences from Phase 1 to Phase 4, the retrain sequence, rate renegotiation sequence and the disconnection procedure. But first, let's look at an exemplary message print-out from SMPA.

2 An exemplary message print-out from SMPA

The best way to understand what SMPA does is to look at an example. The following example displays the actual messages "intercepted" by SMPA on a modem call between a *US-Robotics 56K*

V.90 modem (external modem attached to a PC) and *AOL's* local ISP (831-454-0966) in Santa Cruz of California. The calling modem (*US-Robotics* modem) is connected to a *3620 MainStreet* channel bank through a 6-foot-long analog telephone cord (ideal 2-wire loop). The channel bank is in turn connected to the local class 5 switch through T1 with in-band robbed-bits signalling. The SMPA was "attached" to the T1 lines through a "non-intrusive" high-impedance monitoring mode.

```
ANS/ANSam tone detected at time 0.00
ANS/ANSam tone amplitude modulation index = 0.19
ANS/ANSam tone phase reversal jump = 187.44

CM Detected at time 1.09
Vxx modem call
With PCM/V34 modes
V9x analog available
Analog connection

JM Detected at time 2.03
Vxx modem call
With PCM/V34 modes
V9x digital available
Digital connection

INFO_0a detected at time 3.06
Mandatory rate 3200 supported

INFO_0d detected at time 3.07
Mandatory rate 3200 supported
Mandatory rate 3000 supported
mu-law PCM coding

Tone A to guard tone ratio (in dB) = 5.95

INFO_1d detected at time 4.30
At symbol rate 2400, projected max data rate = 14400
At symbol rate 2743, projected max data rate = 19201
At symbol rate 2800, projected max data rate = 0
At symbol rate 3000, projected max data rate = 24000
At symbol rate 3200, projected max data rate = 28800
At symbol rate 3429, projected max data rate = 0
Measured frequency offset (in Hz) by digital modem = 0.06

INFO_1a detected at time 4.50
Downstream V90 mode selected, symbol rate = 8000
Uinfo = 78
Upstream V34 symbol rate = 3200
Measured frequency offset (in Hz) by analog modem = 0.00
```

```
Rate renegotiation by digital modem at time 18.00

Rate renegotiation by analog modem at time 25.00

Retrain initiated by analog modem at time 27.12

Tone A to guard tone ratio (in dB) = 6.12

INFO_1d detected at time 32.00
At symbol rate 2400, projected max data rate = 14400
At symbol rate 2743, projected max data rate = 19201
At symbol rate 2800, projected max data rate = 0
At symbol rate 3000, projected max data rate = 24000
At symbol rate 3200, projected max data rate = 28800
At symbol rate 3429, projected max data rate = 0
Measured frequency offset (in Hz) by digital modem = 0.04

INFO_1a detected at time 32.50
Downstream V34 mode selected
Downstream V34 symbol rate = 3200
Projected max V34 downstream data rate = 21600
Upstream V34 symbol rate = 3200
Measured frequency offset (in Hz) by analog modem = -0.02

Disconnection by digital modem at time 40.00
```

We now go through the above messages block by block by examining the associated modem start-up signals phase by phase.

3 Modem start-up signals and sequences

3.1 Phase 1 signals

Details of phase 1 signals are described in [1]. There are 3 key signals during phase 1: ANSam (answer tone with amplitude modulation), CM (call menu) signal and JM (joint menu) signal. Figure 1 shows an example of phase 1 signals. SMPA detects and analyzes all these 3 signals.

3.1.1 ANSam signal

After call completion, the answer modem (typically an ISP modem at the digital side of the PSTN) sends out this ANSam signal to the call modem (typically a client modem at the analog side of the

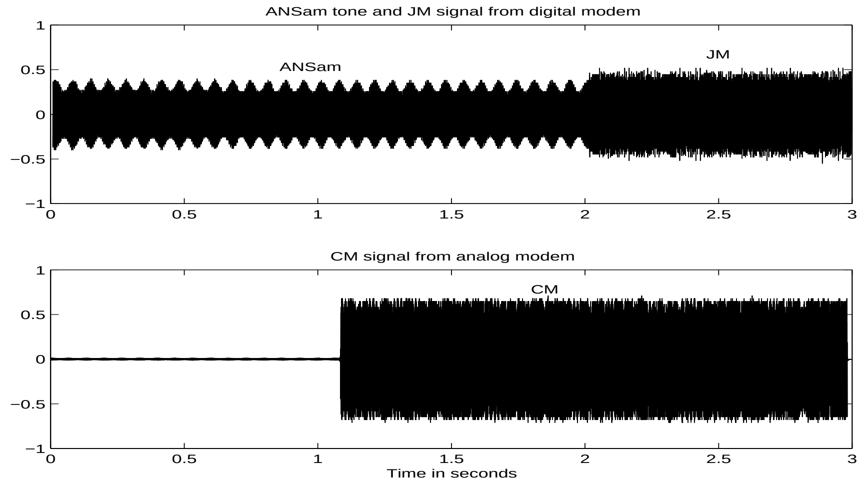

Figure 1: An example of phase 1 signals.

PSTN) to signal the successful call completion and the nature of the answering device (meaning, this is a V90 modem you are calling; this is not a telephone, nor a fax, nor an answering machine etc.). According to [1], this ANSam tone shall meet the following requirements:

1. tone frequency of 2100 Hz at a level of typically -13 dBm;
2. with phase reversals at an interval of 450 ms;
3. with 15Hz amplitude modulation, and the modulation index shall be close to 0.2 so that the modulated envelope ranges in amplitude between 0.8 and 1.2 times its average amplitude.

Requirements 1 and 2 are intended to disable network echo cancellers. Requirement 3 is what distinguishes a V90 modem from other answering devices that may also need to disable echo cancellers such as a fax machine. Such amplitude modulation is even visible from the signal shown in Figure 1. Sage's SMPA will detect this 2100 Hz tone and analyze the phase jump if there are any phase reversals, and then measure the exact 15 Hz amplitude modulation index. So the first message block from SMPA is about this ANSam tone:

```
ANS/ANSam tone detected at time 0.00
ANS/ANSam tone amplitude modulation index = 0.19
ANS/ANSam tone phase reversal jump = 187.44
```

All future signal events are time-stamped in reference to the beginning of the ANSam tone. Therefore, the ANSam detection event is always time-stamped at 0.00 second. The 15 Hz amplitude modulation index is 0.19, in this case, and the phase jump at the phase reversal point is 187.44 degree.

If the measured modulation index is between 0.05 and 0.5, this call will be deemed as a valid V90 modem call by SMPA, and SMPA is triggered to look for the subsequent signals. If the modulation index is out side the [0.05,0.5] range, SMPA will deem this call an invalid V90 modem call (could be a fax call, for example), and keeps looking for another valid ANSam tone.

3.1.2 CM signal

Upon detecting a valid ANSam tone, the calling modem will start sending the CM signal to indicate the nature of the calling device and its potential capabilities. This CM signal is FSK modulated at 300 bits/s according to V.21 [2]. More specifically, this CM signal carries information on call function category (is this a V-series modem call or a T.30 fax call? for example), information on modulation modes (V.34, V.32 and PCM etc.), PCM modem availability and PSTN connection type (digital or analog).

SMPA will demodulate and decode this CM signal, and prints out the relevant information. An exemplary message resulting from this CM signal will look like this:

```
CM Detected at time 1.09
Vxx modem call
With PCM/V34 modes
V9x analog available
Analog connection
```

The above messages indicate that a CM signal has been detected at time stamp 1.09 seconds (referenced to the start of the ANSam signal). The CM signal indicates that the calling device is an ITU V-series modem (call function category); it has both PCM and V.34 modulation modes; V9x (V.90 or V.92) analog modem capability is available on this calling device; and this device is connected to the PSTN with analog 2-wire interface.

3.1.3 JM signal

JM signal has the same nature as CM, except that it is sent from the digital modem to the analog modem in response to the reception of the CM signal. SMPA will demodulate and decode this JM signal. An exemplary message as a result of JM detection will look like the following:

```
JM Detected at time 2.03
Vxx modem call
With PCM/V34 modes
V9x digital available
Digital connection
```

The above messages mean that a JM signal has been detected by SMPA at time 2.03 seconds (referenced to the start of ANSam signal). The JM signal indicates that the answering device is an ITU V-series modem; it has the PCM and V34 modulation modes; the digital V90/V92 capability is available and it is connected to PSTN with digitally.

3.1.4 Signs of potential problems at phase 1

Severe modem incompatibility can result in modem call failure even at phase 1. For a successful modem call, the SMPA should detect and display the following information:

1. On ANSam tone, the modulation index should be close to 0.20 ± 0.05.
2. Both CM and JM should contain the following messages:

```
Vxx modem call
With PCM/V34 modes
```

3. In addition, the CM message should indicate the following:

```
V9x analog available
Analog connection
```

4. The JM message, on the other hand, should indicate the following:

```
V9x digital available
Digital connection
```

Any messages other than those shown above when detected by SMPA imply potential modem compatibility problems. More specifically, any one of the following messages when reported by SMPA indicate potential problems at the phase 1 stage:

```
ANS/ANSam tone amplitude modulation index = 0.00

2100Hz-tone too long, time out

CM not detected, time out

JM not detected, time out

No PCM/V34 modes

V9x not available
```

3.2 Phase 2 signals

Phase 2 signals are used by the modems for channel probing and ranging. The modem capability information and modulation parameters are sent in the 4 INFO sequences. Details of these signals are described in [4] and in [3]. Figure 2 shows an example of the phase 2 signals.

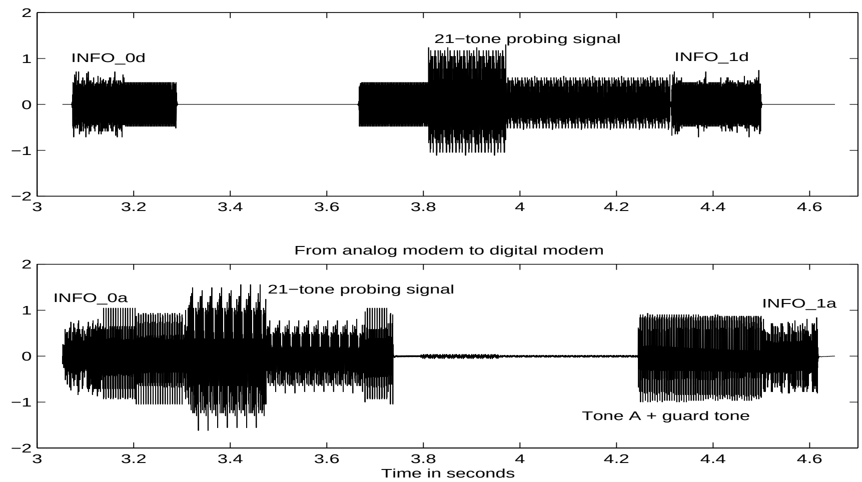

Figure 2: An example of phase 2 signals.

All of the 4 INFO sequences are DPSK (differential PSK) modulated at 600 bits/s and CRC encoded. Sage's SMPA will demodulate all these 4 INFO sequences, perform CRC checking on the "raw" bits, and print out the relevant information content if no CRC errors are found. Besides the INFO sequences. SMPA also measures the tone A to guard tone level ratio for reasons that will be soon clear.

3.2.1 INFO_0d sequence

INFO_0d sequence carries information on the digital modem's capability. SMPA prints out the 3 most important pieces of information:

```
INFO_0d detected at time 2.82
Mandatory rate 3200 supported
Mandatory rate 3000 supported
mu-law PCM coding
```

A well-functioning ISP digital modem must indicate that it supports the mandatory symbol rate of 3200 and 3000. With T1 connection, it should indicate mu-law coding, and with E1 connection, it should indicate A-law coding. Any messages other than those shown above imply potential problems at the digital modem side.

3.2.2 INFO_0a sequence

INFO_0a sequence carries information on the analog modem's capability. SMPA prints out only one crucial piece of information from INFO_0a:

```
INFO_0a detected at time 2.88
Mandatory rate 3200 supported
```

A well-functioning analog modem must indicate that it supports the mandatory symbol rate of 3200. Any messages other than those shown above imply potential problems at the analog modem side.

3.2.3 INFO_1d sequence

INFO_1d sequence is used by the digital modem to send the channel probing results over to the analog modem. SMPA will print out the following relevant information from the INFO_1d sequence:

```
INFO_1d detected at time 3.94
At symbol rate 2400, projected max data rate = 14400
At symbol rate 2743, projected max data rate = 19201
At symbol rate 2800, projected max data rate = 0
At symbol rate 3000, projected max data rate = 24000
At symbol rate 3200, projected max data rate = 28800
At symbol rate 3429, projected max data rate = 0
Measured frequency offset (in Hz) by digital modem = 0.06
```

The above messages mean that if symbol rate 2400 is used, the maximum upstream (from client to ISP) data rate will be 14400 bits/s; if symbol rate 2743 is used, the maximum data rate will be 19201 bits/s; symbol rate 2800 is not supported; if symbol rate 3000 is used, the maximum date rate will be 24000 bits/s; if symbol rate 3200 is used, the maximum data rate will be 28800 bits/s; symbol rate 3429 is not supported; and the digital modem measured a frequency offset of 0.06 Hz on the 21-tone probing signal sent from the analog modem.

3.2.4 INFO_1a sequence

From a client user point of view, this INFO_1a sequence is probably the most useful, as it decides the downstream modem modes (V90 or V34 modes). SMPA should print out messages like the following when the downstream selects V90 mode:

```
INFO_1a detected at time 4.16
Downstream V90 mode selected, symbol rate = 8000
Uinfo = 78
Upstream V34 symbol rate = 3200
Measured frequency offset (in Hz) by analog modem = 0.00
```

The above message block means that, the downstream data flow (from ISP to client) will use the V90 mode, and the symbol rate is fixed at 8000 with PAM (pulse-amplitude-modulation for V90 PCM modem). The "Uinfo=78" is the information needed by digital modem for phase 3. This number should be greater than 66. The upstream data flow (from client to ISP) will select the symbol rate of 3200. Looking back at the information from INFO_1d, one can see the maximum upstream data rate will be 28800 bits/s. The analog modem did not measure any frequency offset on the probing tones sent from the digital modem.

If the analog modem decides to select V34 mode for the downstream traffic, then the messages from SMPA will look like this:

```
INFO_1a detected at time 4.16
Downstream V34 mode selected
Downstream V34 symbol rate = 3200
Projected max V34 downstream data rate = 21600
Upstream V34 symbol rate = 3200
Measured frequency offset (in Hz) by analog modem = 0.00
```

The above message block means that, the downstream data flow will use the V34 mode with symbol rate of 3200 and maximum data rate of 21600 bits/s. The upstream flow will use a symbol rate of 3200 and maximum data rate of 28800 bits/s (from the INFO_1d sequence).

3.2.5 Tone A to guard tone ratio

Tone A (2400Hz) is used by the analog modem during phase 2. For "historical" reasons, tone A is accompanied (added) by a guard tone of 1800 Hz. As defined in section 8.2.1 of V90 [4] and section 10.1.2.1 of V.34 [3], the guard tone shall be 1 dB higher than tone A, hence the correct tone A to guard tone ratio should be -1 dB. However, such definition can be easily confused with the definition of the INFO_1a and INFO_0a sequences, which also require the presence of the guard tone, and the guard tone shall be 6 dB lower than the INFO signal. So, the modems from some manufacturers, such as the *US-Robotics* modem we used, the tone A to guard tone ratio has been measured to be close to 6.00 dB. This is not correct, strictly speaking. Some newer PCs with built-in modems under Windows XP operating system do have correct tone A to guard tone ratio close to -1.00 dB.

It is unlikely that such mis-interpretation of ITU specification will result in modem call failures.

But this measurement does show which modem manufacturers paid real attentions to the finest details of the ITU specifications.

3.2.6 Signs of problems at phase 2

Both the INFO_0d and INFO_0a sequence shall display the message

```
Mandatory rate 3200 supported
```

If such message is absent, that modem is not compliant with the ITU V.90/V.34 standards.

Likewise, INFO_1d sequence shall never indicate "0" maximum data rate at symbol rate of 3200.

The tone A to guard tone ratio should be close to -1.00 dB, although any other numbers may or may not cause problems.

Ideally, the INFO_1a sequence should always indicate this:

```
Downstream V90 mode selected, symbol rate = 8000
```

This implies that the downstream direction (which is more important to a user than the the upstream) is using V.90 mode with data rate at least 28000 bits/s and as high as 56000 bits/s.

If, on the other hand, the INFO_1a sequence displays the following message:

```
Downstream V34 mode selected
Downstream V34 symbol rate = 3200
Projected max V34 downstream data rate = 21600
```

This implies that the downstream has chosen V.34 mode, with maximum data rate 21600 bits/s. In V.34 mode, the data rate falls between 2400 bits/s and 33600 bits/s.

Although "hidden" from "uneducated" users, whenever the downstream does not choose V.90 mode, potential problems are implied. These problems could be related to the telephone networks (transmission problems such as bad loop lines and incorrectly configured T1 lines with excessive robbed signalling bits or B8ZS mismatches etc). Or these problems can be caused by pure modem "mismatch" (benign incompatibility). In the example message shown in section 2 for the modem call between *US-Robotics* modem and *AOL's* ISP in Santa Cruz, the *US-Robotics* modem first selected V.90 mode for the downstream, but quickly, a few seconds later after retraining, it chose the V.34 mode with maximum downstream data rate only 21600 bits/s on a connection where the analog loop line is only 6 feet long. We tried tens of different ISPs here in Santa Cruz. Almost all of them will allow the analog call modem to choose V.90 mode for downstream except this *AOL* ISP. Given everything else being the same (same analog modem with the same analog connection), it appears the digital T1 lines leading to *AOL's* ISP may have potential problems, or *AOL's* ISP modem pool has some "defects".

Neither INFO_1d nor INFO_1a should indicate any measured frequency offset larger than 1.00 Hz. If one sees a message like the following:

```
Measured frequency offset (in Hz) by digital modem = 5.00
```

This means that the signals from the analog modem contains 5.00 Hz frequency offset as seen by the digital modem. This could be caused by hardware defects (clock skew, for example) on the calling analog modem. However, if one sees the following message:

```
Analog modem unable to measure frequency offset accurately
```

This means that the analog modem is not capable of measuring frequency offset to an accuracy of 0.25 Hz. This may or may not cause any problems, but it does point out the incompetence of the modem's firmware.

3.3 Phase 3 and phase 4 signals

Phase 3 is for modem's internal equalizer and echo canceller training and digital impairment learning. Digital impairment learning (the "bong-bong" or "gha-gha" sound that one heard on a modem call) only applies to the V.90 mode. No information is exchanged in phase 3, therefore SMPA does not print anything for this phase.

Phase 4 is the final training. Most of the information is for the modem's internal use, so no information will be intercepted by SMPA either for this phase.

Figure 3 shows an example of the phase 3 and phase 4 training signals.

However, SMPA does monitor the successful completion of the phase 3 and phase 4 trainings. If the trainings are successfully completed in time, no message will be printed. But if the trainings are not completed in time (within 20 seconds from the end of phase 2), the following message will be printed and all subsequent signals are ignored unless there is a new modem call coming in.

```
Phase 4 not detected, time out
```

4 Rate renegotiation, Retrain and Disconnection

After detecting the completion of phase 4 signals, SMPA will from this point on keep watching these 3 events: rate renegotiation, retrain and disconnection. In fact, retrain is being monitored as early as after phase 2.

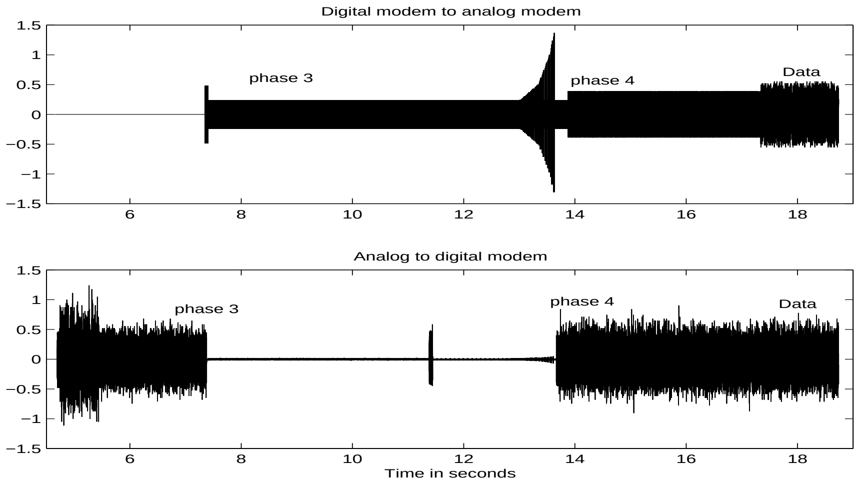

Figure 3: An example of phase 3 and phase 4 signal sequences. In this example, the downstream (from digital to analog at the top) has been selected during phase 2 to be V90 mode. If V34 mode were chosen, the signal sequence would look different, but similar to that shown in the bottom for the upstream direction where V34 mode is always used.

4.1 Rate renegotiation

Anytime after phase 4, whenever a modem wishes to change the data rate (because of excessive data errors, for example), the current data transfer will be interrupted, and a rate renegotiation sequence will be started. The other modem shall also stop the data transfer and respond to the rate renegotiation request in a timely manner. This whole sequence may take up to 4 seconds. Figure 4 shows an example of the rate renegotiation sequence.

Sage's SMPA will intercept all rate renegotiation sequences. Whenever the digital modem initiate a rate renegotiation sequence, the following message will be reported by SMPA:

```
Rate renegotiation by digital modem at time 20.00
```

Likewise, if the analog modem initiates a rate renegotiation, SMPA will report:

```
Rate renegotiation by analog modem at time 25.00
```

4.2 Retrain

Retrain is a drastic measure taken by either modem to retrain and resynchronize the modem receivers. Retrain can happen during phase 3, phase 4, rate renegotiation and data transfer. If a modem wishes to initiate a retrain, it will stop its current activity (phase 3 or 4 trainings, rate renegotiation or data transfer), and go back to the signal exchanges in phase 2 except there are no

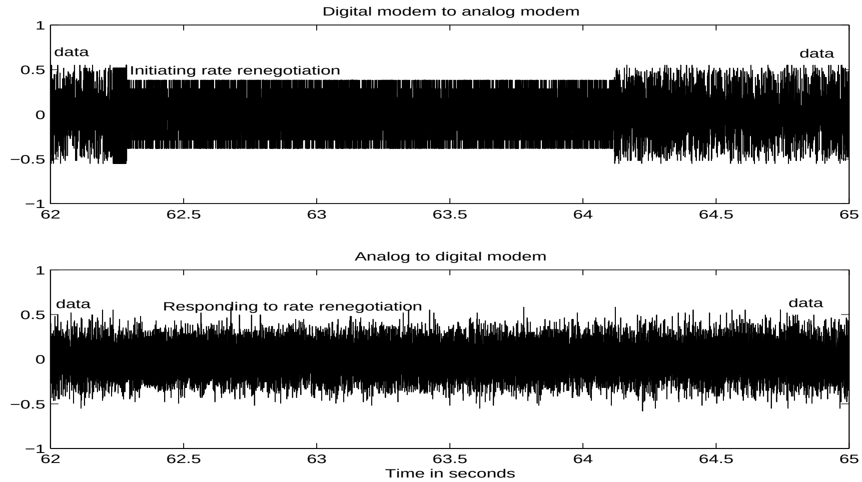

Figure 4: Rate renegotiation signal sequence. In this example, the downstream uses V90 mode. If V34 modem were chosen, the signal flow on top would look different (similar to that at the bottom).

INFO_0d and INFO_0a sequences. The other modem will respond to the retrain request by also going to the phase 2 signal exchanges. The retrain sequence may take up to 8 seconds.

Sage's SMPA will intercept all retrain sequences. Whenever a retrain occurs, SMPA will report messages like the following:

```
Retrain initiated by analog modem at time 18.00

Tone A to guard tone ratio (in dB) = 6.12

INFO_1d detected at time 19.15
At symbol rate 2400, projected max data rate = 14400
At symbol rate 2743, projected max data rate = 19201
At symbol rate 2800, projected max data rate = 0
At symbol rate 3000, projected max data rate = 24000
At symbol rate 3200, projected max data rate = 28800
At symbol rate 3429, projected max data rate = 0
Measured frequency offset (in Hz) by digital modem = 0.04

INFO_1a detected at time 19.38
Downstream V34 mode selected
Downstream V34 symbol rate = 3200
Projected max V34 downstream data rate = 21600
Upstream V34 symbol rate = 3200
Measured frequency offset (in Hz) by analog modem = -0.02
```

In the above example, the retrain was initiated by the analog modem. If the retrain is initiated by the digital modem, SMPA will display:

```
Retrain initiated by digital modem at time 18.00
```

And the subsequent messages will be similar.

4.3 Disconnection

Sage's SMPA has no access to the SS7 or ISDN supervision channel, so the disconnection event is detected by continuously monitoring the signal power level on the circuit.

Since both V.90 and V.34 are "continuous" synchronous modems, there are no silence gaps once data transfer starts (after phase 4). Even if the application layer (your PC or the server, for example) has nothing to send or receive, the circuit is always "hot". Therefore, any silence gap longer than 300 ms during data transfer will be detected by SMPA as "disconnection". If the digital modem goes quiet first, the SMPA will display:

```
Disconnection by digital modem at time 27.47
```

If the analog modem goes quiet first, the SMPA will display:

```
Disconnection by analog modem at time 30.00
```

Figure 5 shows an actual example of the disconnection event. In this example, the digital modem became quiet (disconnected) at time 68.56 seconds, and 500 ms later, the analog modem was also disconnected. In this case, SMPA will report the following message:

```
Disconnection by digital modem at time 68.56
```

Keep in mind that, for the example shown in Figure 5, although the digital modem was disconnected first, the analog modem (or, more correctly, the client application) may have requested the disconnection in the first place.

4.4 Signs of problems with rate renegotiation, retrain and disconnection

4.4.1 What's wrong with too many rate renegotiations and retrains

A typical analog modem (PC built-in or external) will shut off the audio (speaker) after phase 4 when the data transfer starts, so the rate renegotiation, retrain sequences are some "hideous" things that the modems are constantly doing hidden from the users. The net effect of rate renegotiation and retrain is that the effective data rate is much lower than that "advertised" by the user's PC. For example, since a rate renegotiation can take up to 5 seconds, if rate renegotiation occurs every 10 seconds, the effective data rate is only half that being advertised, plus the data rate might be

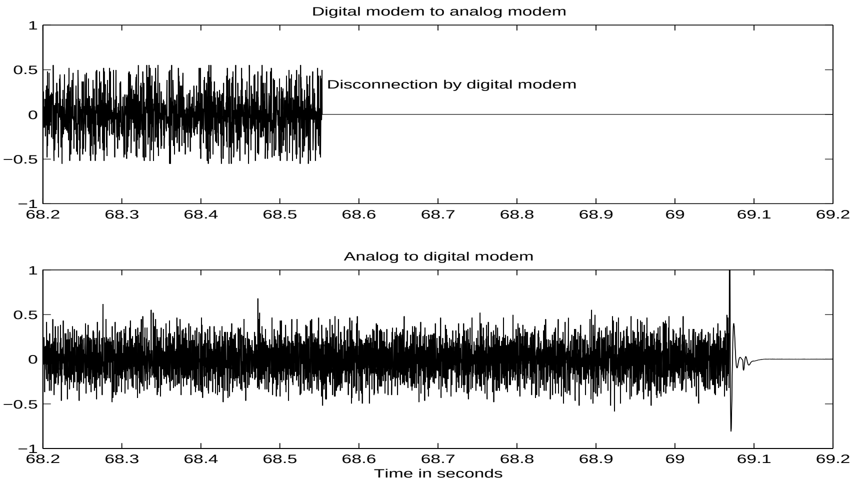

Figure 5: An actual example of the modem disconnection sequence.

constantly reduced and the PC application never updates the actual data rate information. The net effect of retrain sequence, of course, is even worse.

A stable modem connection should not have excessive number of rate renegotiations and retrains. If Sage's SMPA displays messages like the following:

```
Rate renegotiation by analog modem at time 100.00

Rate renegotiation by digital modem at time 110.00

Rate renegotiation by digital modem at time 130.00

Rate renegotiation by analog modem at time 140.00

Rate renegotiation by analog modem at time 150.00
```

then this particular modem call is definitely not acceptable from the customer satisfaction point of view, although the "poor" user may never know it. But a smart user should notice that the actual file downloading rate is far slower than the advertised connection rate of, say, 52000 bits/s, or his/her web browser feels so sluggish and freezingly slow.

If a rate renegotiation sequence cannot even be successfully finished, a retrain sequence will follow. So one will commonly see messages like the following intercepted by SMPA:

```
Rate renegotiation by analog modem at time 150.00

Retrain initiated by analog modem at time 151.00

Tone A to guard tone ratio (in dB) = 6.12
```

```
INFO_1d detected at time 152.00
At symbol rate 2400, projected max data rate = 14400
At symbol rate 2743, projected max data rate = 19201
At symbol rate 2800, projected max data rate = 0
At symbol rate 3000, projected max data rate = 24000
At symbol rate 3200, projected max data rate = 28800
At symbol rate 3429, projected max data rate = 0
Measured frequency offset (in Hz) by digital modem = 0.04

INFO_1a detected at time 152.10
Downstream V90 mode selected, symbol rate = 8000
Uinfo = 78
Upstream V34 symbol rate = 3200
Measured frequency offset (in Hz) by analog modem = -0.02
```

If repeated rate renegotiations are like minor scratches on your feet, frequent retrains are like sores in your eyes. If frequent retrains are detected by SMPA, this modem call is sure not very satisfactory.

Frequent rate renegotiations and retrains may be caused transmission issues such as impulse noise or call waiting type of interference signal, or detectable clock skews between the two modems, or as a result of algorithmic software/firmware bugs inside the modems.

Figure 6 shows a real example of repeated rate renegotiation and retrains that actually occurred between a *US-Robotics* modem and *AOL's* ISP modem pool in Santa Cruz of California. The best way to examine the signal is to match the signals with the following messages from Sage's SMPA using the time stamp information. During the whole 30 seconds period shown in Figure 6, there were not any practical data transfer except the repeated rate renegotiation and retrains. Even worse, after the second retrain initiated by the analog modem, the downstream traffic was downgraded to V34 mode with maximum data rate at no more than 21600 bits/s. This happened on a connection where the analog loop line is merely 6 feet long.

For the signal sequences shown in Figure 6, SMPA intercepted the following messages:

```
Rate renegotiation by analog modem at time 36.93

Retrain initiated by digital modem at time 41.39

Tone A to guard tone ratio (in dB) = 6.06

INFO_1d detected at time 12.59
At symbol rate 2400, projected max data rate = 14400
At symbol rate 2743, projected max data rate = 19201
At symbol rate 2800, projected max data rate = 0
At symbol rate 3000, projected max data rate = 24000
At symbol rate 3200, projected max data rate = 28800
At symbol rate 3429, projected max data rate = 0
```

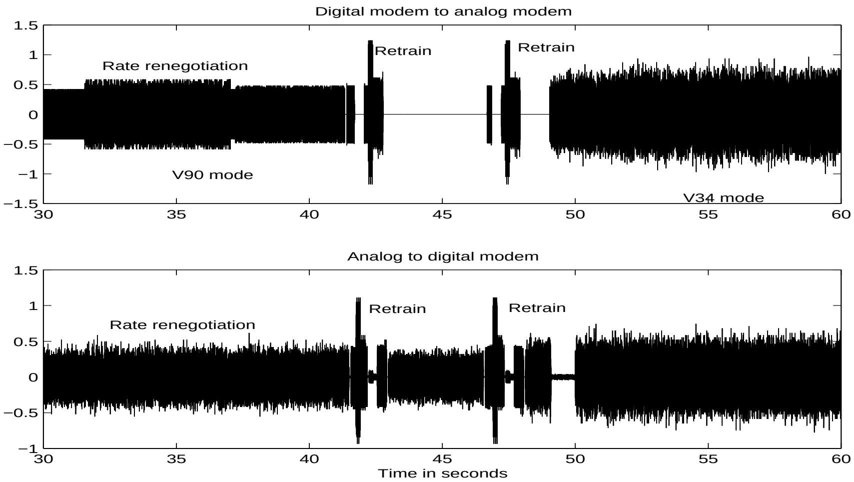

Figure 6: A real example of repeated rate renegotiation and retrains. Further explanations of the figure are in the messages from SMPA shown in the text.

```
Measured frequency offset (in Hz) by digital modem = 0.04

INFO_1a detected at time 42.80
Downstream V90 mode selected, symbol rate = 8000
Uinfo = 78
Upstream V34 symbol rate = 3200
Measured frequency offset (in Hz) by analog modem = 0.00

Retrain initiated by analog modem at time 46.61

Tone A to guard tone ratio (in dB) = 6.02

INFO_1d detected at time 47.74
At symbol rate 2400, projected max data rate = 14400
At symbol rate 2743, projected max data rate = 19201
At symbol rate 2800, projected max data rate = 0
At symbol rate 3000, projected max data rate = 24000
At symbol rate 3200, projected max data rate = 28800
At symbol rate 3429, projected max data rate = 0
Measured frequency offset (in Hz) by digital modem = 0.04

INFO_1a detected at time 47.95
Downstream V34 mode selected
Downstream V34 symbol rate = 3200
Projected max V34 downstream data rate = 21600
Upstream V34 symbol rate = 3200
Measured frequency offset (in Hz) by analog modem = -0.04
```

4.4.2 Graceful and disgraceful, normal and abnormal disconnections

One of the goal of this SMPA is to help determine if a modem call has experienced an abnormal disconnection. To define abnormal disconnection, let's first examine the conditions where a normal disconnection should occur. A modem call should only be disconnected under the following circumstances:

1. The client (typically, the calling analog modem) requested the disconnection.
2. The ISP server detected invalid user name or password, and shut off the "illegal" connection.
3. Modem incompatibilities were detected. If the two modems speak no common "language", then the connection has to be disconnected. For example, if one modem indicates V90 mode, while the other one is only capable of V32, then no further communication is possible beyond phase 1.
4. Physical disconnection of the telephone circuit. If the telephone cord is knowingly or unknowingly unplugged from the modem, or the telephone circuit is suddenly cut off, then of course, both modems will disconnect either forced by the telephone network's on-hook signalling or by the modem's own internal time-out after seeing no response from the other modem.

On the other hand, there are infinite number of scenarios of abnormal disconnections. Typically scenarios are:

1. One modem (either the analog modem or the digital modem) disconnects unilaterally without informing or being requested by the other modem. Such "rude" behavior is a sign of software or configuration bugs.
2. False telephone network supervision signals are detected. For example, the ISP digital modem may have falsely detected some SS7, PRI/ISDN or robbed-bit signalling messages indicating the analog modem has disconnected the circuit by going on-hook, although the analog modem has never really done so. Likewise, the analog modem may have falsely detected "unstable" DC supervision signal indicating the digital modem has gone "on-hook". Such problems could be the fault of the telephone signalling network, or the fault of the modem's supervision detection modules.
3. Strong interference signals such as bursty impulsive noise or call-waiting signals may overwhelm or confuse especially the analog modem, causing it to disconnect. This is the fault of the modem. The modem algorithm should be designed more resilient and more robust.
4. Lousy telephone line or poor modem algorithms cause the modems not to be able to complete the phase 1 to phase 4 trainings. Eventually, the modems will time out after repeated retrains.

To use SMPA for diagnosing abnormal disconnection, one must be aware of the following subtleties.

Theoretically, if a modem wants to terminate a connection, it shall follow the graceful clear down procedure specified in [4] and [3]. According to this procedure, the modem that requests termination should always initiate a rate renegotiation sequence first. During the rate renegotiation process, it will request the other modem to lower the data rate to zero, meaning disconnection. If such graceful termination procedure is followed, then Sage's SMPA will intercept the following messages:

```
Rate renegotiation by analog (digital) modem at time 500.00

Disconnection by digital (analog) modem at time 501.00
```

If a disconnection event follows a rate renegotiation event within one second or so, then this disconnection is a graceful one.

Unfortunately, in the practical world, the graceful termination procedure is rarely followed, because the applications in the client's PC or those at the ISP's servers have other "brutal-force" ways of terminating a modem connection. More specifically, for example, when a PC user decides to disconnect by clicking the "disconnection" button or icon on his/her PC, this disconnection request may be encoded as an application layer packet, and is sent to the remote ISP server. Upon detecting the disconnection message packet, the remote server will then signal to the telephone network that it wants to go "on-hook". It also tells its own modem to stop sending further data. The analog modem will be shutdown either by itself after receiving no data from the remote modem (time out) or forced to shut down after detecting on-hook signalling from the other end. In short, the disconnection process is handled at the application layer in conjunction with the telephone network signalling. In such situations, the modem will not follow the graceful termination procedure. In fact, the modems were not even aware of the user's desire to disconnect, since they are handled at the application layer, instead at the data link layer. Under these circumstances, Sage's SMPA will only detect an abrupt disconnection like:

```
Disconnection by digital modem at time 501.00
```

This may seem very "disgraceful" and abnormal, but it could just be a legitimate disconnection requested by the client.

So, in conclusion, the SMPA can detect disconnection. But it can not determine whether such disconnection is a "voluntary" one as requested by the client, or a "rude" one initiated by a modem unilaterally. The users of SMPA have to use other messages from SMPA to deduce the a reasonable diagnosis. For example, if SMPA reports:

```
Phase 4 not detected, time out
```

This is definitely an abnormal disconnection that most likely is caused by a very bad connection (telephone network problem). The message indicates that the connection is so bad that the modems can not even complete the four phases of trainings. Likewise, other time out messages from SMPA such as:

```
INFO_1a (or IFNO_1d, or INFO_0a or INFO_0d) not detected, time out
```

all indicate the same abnormal premature disconnection due to the modem's failure to complete the 4 phases of trainings. While the telephone network is mostly to blame, software bugs inside the modems themselves can also contribute to such problems.

The disconnection time stamp offers additional clue. One can argue that a normal dial up modem call should last at least a minute. If the SMPA reports a disconnection with time stamp less than 60.00 seconds, then such disconnection is very likely an unhappy one, especially if the disconnection is preceded with repeated rate renegotiations and retrains.

Other information from INFO_1a and INFO_1d can also be used to indicate how good this modem call is. The INFO_1a should indicate that the downstream mode is V90 mode. If V34 mode is chosen, the connection is not ideal, although it is not necessarily a problem. A customer is much happier if his/her modem always trains up to V90 modem on the downstream. The projected maximum data rate indicated by INFO_1d should also be reasonably high.

References

[1] "Procedures for starting sessions of data transmission over the public switched telephone network," *ITU-T Recommendation V.8*, November, 2000.

[2] "300 bits per second duplex modem standardized for use in the general switched telephone network," *ITU-T Recommendation V.21*, extract from the *Blue Book*, 1993.

[3] "A modem operating at data signalling rates of up to 33600 bits/s for use on the general switched telephone network and on leased point-to-point 2-wire telephone-type circuits," *ITU-T Recommendation V. 34*, 1998.

[4] "A digital modem and analog modem pair for use on the public switched telephone network (PSTN) at data signalling rate of up to 56000 bit/s downstream and up to 33600 bit/s upstream," *ITU-T Recommendation V.90*, 1998.