Low Cost Wireless Sensor Network

APPLICATION DOCUMENT FOR DRF1110N V1.00

1. INTRODUCTION

This document introduces the features of DRF1110N in wireless sensor network application and describes the configuration of parameters in different sleep modes. It is also involved in power consumption calculation and power management on sensor. In the end of the document an example of practical solution based on temperature & humidity sensor is demonstrated.

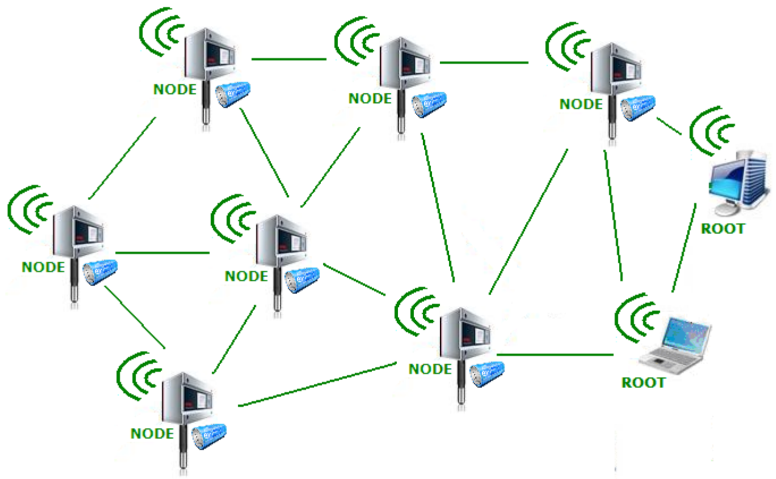

Figure 1: Wireless Sensor Network Topology

The wireless sensor network usually is consisted of many low-cost, low-power sensor nodes with the ability of self-calculation and communication and can fulfill the intelligent monitoring tasks automatically according to the environment. It can be used in military, industrial control, environment monitor, medical treatment, home automation and other applications without presence of human beings.

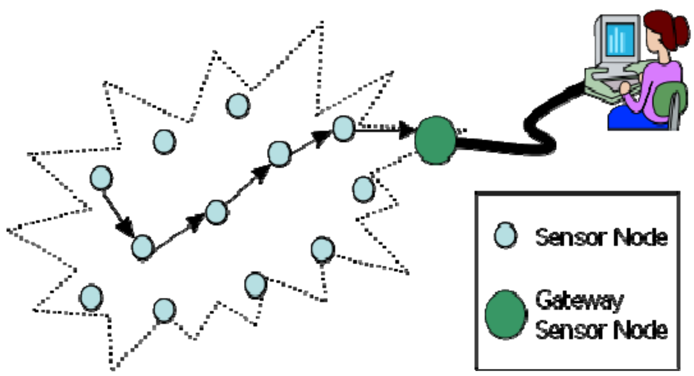

Figure 2: Multi-level Routing Diagram

The wireless sensor network applications need to periodically read the real time data from all of the nodes in the network with features showed as below:

- Real-time. It needs to fulfill the data collection of the whole network in milliseconds level.
- Periodically. The data are collected periodically and the time interval is very short, which usually are several minutes or dozens of minutes.
- Low power consumption. In such applications the nodes are usually powered up by battery so low-power is the key requirement on wireless network algorithm.
- Mobile. The network nodes are mobile and the network topology will change from time to time.
- Main-sub mode. The data collection is launched by the concentrator. When the node module receives the READ command, it accesses the data from sensor (sensor) and then uploads the data to concentrator.

Users can easily realize these functions by simply configuring the network modules DRF1110N and the concentrator will automatically collect data from all nodes, partial nodes or one specific node at predefined interval. Related parameters such as data read command, data collection interval, etc. can be stored into the non-volatile memory area of the concentrator module. By adopting synchronous sleep mode or hybrid sleep mode, the low power consumption of network node can be realized. All of the node modules and concentrators can enter sleep mode. The synchronous sleep mode doesn't need wake-up process and can reduce the power consumption to the least. The hybrid sleep mode can improve the robustness of network, in which mode when some nodes can't enter synchronous sleep mode because of interferences, these nodes will enter into asynchronous sleep mode. The MNET III network protocol adopts multi-path algorithm so the data frames can be sent through multiple routes and channels. When there are more than one concentrator in the network, the data will be collected in parallel so the data output of the whole network can be improved distinctively.

2. POWER MANAGEMENT

The DRF1110N modules in MNET III protocol network adopts active power management mode in which mode the DRF1110N module control the sleep and wake-up of sensor. Users can use I/O port or UART interface to realize this function. The DRF1110N module itself also can enter into sleep mode with low power consumption.

- **I/O Port Wake-up**: The ACT pin of module can be used to wake up the sensor. When DRF1110N module needs to collect data from device, it can reverse the output level to wake up the device. After waiting for "TX delay" time, the DRF1110N module send "Read" command to sensor through UART interface. Generally the sensors need some time to become stable after power-up so "TX delay" should be carefully considered in order to get effective data from the sensor.

If the module is configured with Handshake ACK Packet parameter, DRF1110N will send the ACK Packet to the sensor after the module receives the data from it successfully. If the module can't receive the response from the sensor in the preset time, it will reverse the output level of ACT pin to enable the sensor into sleep mode after time-out.

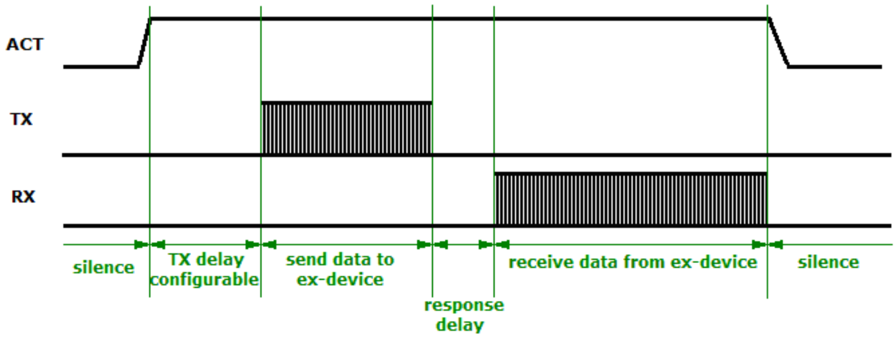

Figure 3: I/O Port Wake-up Timing Sequence

- **UART Wake-up:** DRF1110N module communicates with sensor through UART interface so the module also can use the UART to wake up sensor without occupying extra I/O port. When DRF1110N needs to collect data, it can send a string of repeated bytes (the string length can be variable) to wake up the sensor and then send Read command to collect data. I/O port wake-up is more flexible than UART wake-up but it occupies an extra pin. With conditions permitted, I/O port is the better choice.

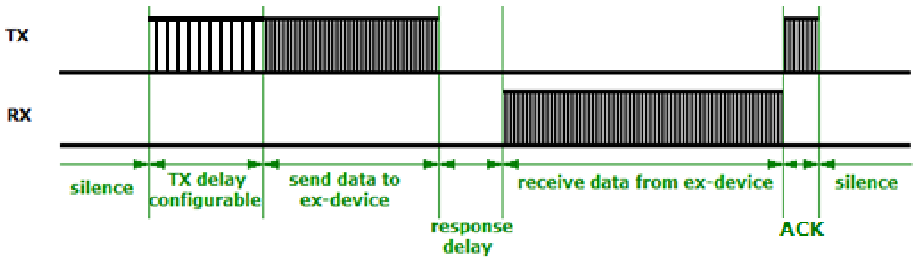

Figure 4: UART Wake-up Timing Sequence

3. SYNCHRONOUS SLEEP MODE

In this mode "work time slice" and "sleep time slice" are synchronized by broadcasting the synchronous sleep packet triggered by concentrator. The alignment error of time slice between two neighboring nodes is less than 1ms. The sleep message is broadcasted by concentrator at the end of "work time slice", which the message contains the length of "sleep time slice". There is no restriction on "work time slice" and it can be adjusted dynamically according to application, which the network can enter into sleep mode at once if there is no data transfer without waiting for the end of the predefined "work time slice" or enter into sleep mode only after data transfer is finished.

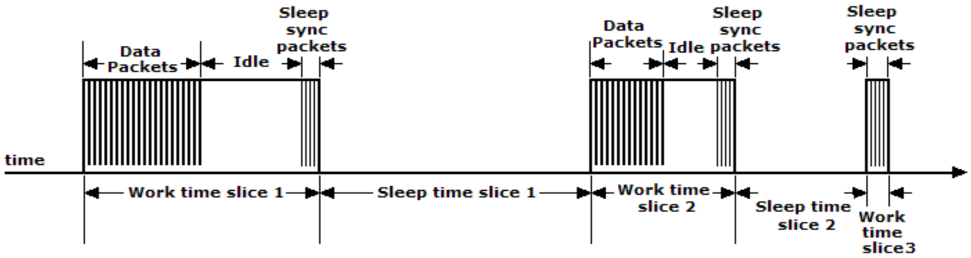

Figure 5: Synchronous Sleep Mode

The "work time slice" and "sleep time slice" can be changed dynamically by concentrator module. In Figure 5, the lengths of "work time slices" /"sleep time slices" are different. In "work time slice 3" there is no data transfer and only the "synchronous sleep packet" (sleep sync packets) is broadcasted. For wireless sensor network, the data transfer is the process of collecting the sensor data and can be described as below:

- The concentrator sends "Read" command to sensor nodes at the beginning of "work time slice". The destination addresses can be broadcasting, multicasting or unicasting (seeing related explanation in function verification section of datasheet).
- When node module receives the "Read" command and finds the destination address of packet matches its own, it will wake up the sensor through ACT pin or UART interface; Meanwhile it will resend the "Read" command to other nodes as relay node.
- In order to guarantee the success of collection, the node module will wait for "Tx delay" time and then send read command to sensor and wait for the response.
- After receiving the response from sensor or time-out, the node module will change the level of ACT (in I/O wake-up mode) to let the sensor enter into sleep.
- If the node module gets the correct sensor data, it will send it to concentrator.
- In the idle time, the other node modules can act as relay nodes to pass on the sensor data of targeted node module to the concentrator.
- The concentrator receives the responded data packets from targeted sensor nodes (or one node if unicasting) continuously.
- The concentrator can stop the data collection after a certain period (configurable) assuming the data transfer is finished and broadcast synchronous sleep packet containing the length of "sleep time slice".
- When the node module receives the synchronous sleep packet, it will relay broadcasting packet to other nodes. In order to improve the reliability of broadcasting packet, it might repeat the relaying process by several times which can be configured.
- After relaying the broadcasting in preset times, the node module will enter into sleep mode till the "sleep time slice" is finished. The whole process of data collection launched by the concentrator then is finished.

For synchronous sleep mode users only need to configure the modules simply by configuration tool or AT commands. Parameters concerning synchronous sleep mode include "Sync Interval", "Repeat", "Sleep" (in Basic RF Configuration section of tool) and

"Predefined broadcasting cmd" in Protocol configuration section.

- **Sync Interval (s):** If this parameter is not zero, the synchronous sleep mode will be enabled automatically. This parameter defines the initialized "sleep time slice" after power-on. It also can be changed by AT command and only is available for concentrator module. In the "work time slice", the concentrator will broadcast synchronous sleep packet when the data transfer in the network is finished.
- **Repeat:** In wireless sensor network applications, the sensor data needs to be collected at intervals. When this option is enabled, the concentrator will broadcast predefined broadcasting command (or newly changed command) periodically by taking "Sync Interval" as "sleep time slice". From the angle of view of users the sensor data will be uploaded to the concentrator in a way like bubbling. This option also can be changed by AT command and only is available for concentrator module.
- **Sleep:** In synchronous sleep mode, the node modules will forcibly execute this mode even if this option is not enabled. In asynchronous or hybrid sleep mode it must be enabled for node and concentrator modules in order to enter corresponding sleep mode.
- **Predefined broadcasting cmd:** Users can set "predefined broadcasting cmd" as the "Read" command. When the concentrator receives the same content as predefined broadcasting command from the host, it can use the simplified packet to replace the predefined command packet and improve the network speed and save data collection time. The "predefined broadcasting cmds" are stored into the nonvolatile memory of modules. When the concentrator detects the parameters have been set when power-on, it will fulfill the data collection at intervals and control the sleep of node modules. No extra process is needed from the application level by users. Besides that, the "predefined broadcasting cmd" also can be used:
    1) Packet conversion: If there are several types of sensors in the network and different sensors need different "Read" commands, users can set different "predefined broadcasting cmd" for concentrator and node modules to collect data from different sensors. E.g. users can send cmd A to concentrator and node modules send cmd B/C/D to external device (different sensors)
    2) Force to use broadcasting for some special usage. For example there is no wildcard in broadcast address or the broadcast address is omitted by some kind of contracted protocols.

Commands related to synchronous sleep mode include ATCR, ATCO and ATCS. Please check the command set section in datasheet for more details.

4. HYBRID SLEEP MODE.

In synchronous sleep mode the node modules might not enter into sleep mode when the synchronous sleep packet is missed because of outside interferences or the power failure of concentrator module. The power consumption of node modules will be increased distinctively. In order to overcome this shortcoming, users can adopt hybrid sleep mode--synchronous sleep mode is main and asynchronous sleep mode is auxiliary. In this mode the nodes without receiving broadcasted synchronous sleep packet can enter into asynchronous sleep mode.

In asynchronous sleep mode, the node modules enter into sleep mode from time to time according to the parameter “Sleep-Wake Rate” which is the ratio of “Auto Sleep Timeout” to “Auto Wake Slot” in advanced parameters section of configuration tool. The “Auto Wake Slot” is related to the RF data rate, which is usually in millisecond level. If the node module detects there is a data flow in the network in the period of “Auto Wake Slot”, it will enter into normal working mode. We can use an example to demonstrate the power consumption. Assuming the module consumes 0.5uA current in sleep mode and 22mA in normal receive mode. The power consumption of asynchronous mode is easy to calculate with the parameter "Sleep -Wake Ratio". For example, if the "Sleep-Wake Ratio" is set to 1000, the average current consumption is (0.5uA*1000+22Ma*1)/1001=22.5uA.

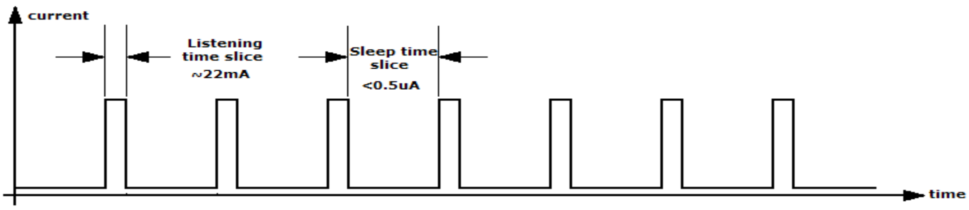

Figure 6: Power Consumption in Asynchronous Sleep Mode

Not liking synchronous sleep mode, the data transfer can’t be done at the beginning of a “work time slice” in hybrid sleep mode and it needs to wake up all nodes or at relaying nodes first. If there are any missing nodes which are still in sleep mode, they also can be waked up in the data transfer process in the network.

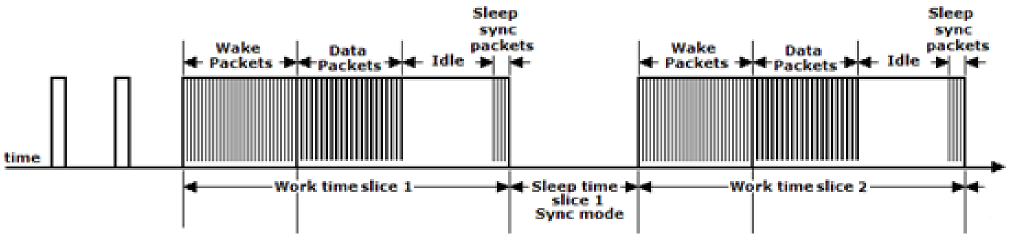

Figure 7: Data Transfer in Hybrid Sleep Mode

Comparing to synchronous sleep mode, the time for waking up the whole network in this mode is increased and it seems to increase the power consumption of node modules. However, the sensor needs a short period to become stabilized after being evoked (usually powered up by node module) and outputs the sampling data to node module. For a pure synchronous sleep mode, the RF parts of all the node modules in receive status and the node modules wait for the data from sensor. There is no data flow in the network till the data sampling from sensor is finished. For hybrid sleep mode the short period can be used to evoke other nodes so the real work time slice will not be increased distinctively so it improves the reliability of network by sacrificing a little power consumption.

Besides the parameters mentioned in synchronous sleep mode, it also needs to make adjustment on other parameters such as "Sleep-Wake Rate" and "Sleep".

- **Sleep-Wake Rate**: It is the ratio of "Auto Sleep Timeout" to "Auto Wake Slot" in advanced parameters section of configuration tool. The value of this parameters ranges from 0 to 2500. Larger value means lower power consumption but longer wake-up time and lower response of modules so this parameter should be refined according to the actual situation of network. When there are mixed needing sleep modules and none-needing sleep modules in the same network, this parameter also need to be set to the same for those none-needing sleep modules in order to improve the success rate of evoking sleeping modules.

- **Sleep:** For asynchronous sleep mode and hybrid sleep mode, this option must be enabled in order to let modules enter into corresponding sleep mode even though "Sleep-Wake Rate" is not zero.

The parameters related to asynchronous sleep mode can be configured through configuration tool and will be stored into nonvolatile memory of module. In principle the parameters should be set before networking so it is not recommended to revise related parameters in the run of network. The asynchronous sleep period is calculated according to "Sleep-Wake Rate" and other parameters. After choosing the default RF data rate (RF baud Def), users can click the "Advanced<<" to expand the tool interface.

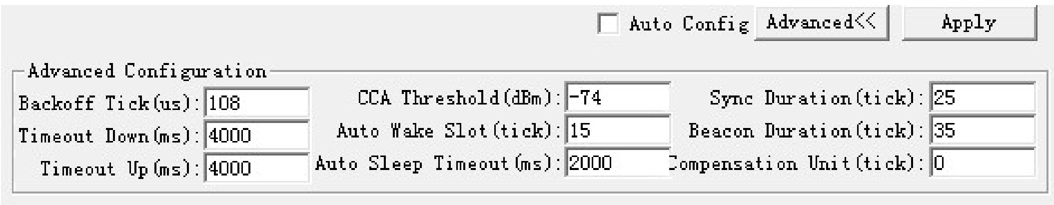

Figure 8: Advanced Parameters

The length of wake-up time (or monitoring time) is the result of "Backoff tick" multiplying by "auto wake slot", which the two parameters are calculated automatically after choosing "RF baud Def". E.g. if the "Auto Wake Slot (tick)" is 15 tick and "Backoff Tick" is 108, the wake-up time (or Auto wake slot (us)) is 108*15=1620us. The length of sleep time in asynchronous sleep mode can be calculated by "Sleep-Wake Rate" multiplying by "Auto Wake Slot". Supposing the "Auto Wake Slot" is 1620us and "Sleep-Wake Rate" is 100, the length of sleep mode is 100*1.62ms=162ms.

5. POWER CONSUMPTION CALCULATION

The parameters needing to calculate the power consumption of wireless sensor network are showed as below:

1) The number of network nodes **N**;
2) The number of network concentrator **n**;
3) The length of data frame uploaded by node module **L**;

4) The RF data rate **B** (kbps);
5) The delay time of external sensor **Td** (ms);
6) The period of wake and sleep in asynchronous sleep mode **Ts** (ms);
7) The idle time-out of concentrator **To** (ms)
8) The receive current **Ir** (mA), transmit current **It** (mA), sleep current **Is** (mA) and PLL calibration current **Ic** (mA) of modules. The typical values are: Ir: 20mA, It: 33~110mA, Is: 0.5uA and Ic: 5mA.

Supposing the features of the wireless sensor network are:

1) The UART data rate of concentrator is 1/2 of its RF data rate: **B**/2;
2) Each routing level has 2 nodes at least or more nodes. When node A is uploading data to the higher level of node, other nodes in the same routing level can receive data from another node from lower level so that the concentrator can get continuous data stream.
3) There is no outside interference in the network, the communications among nodes are steady and there is no isolated node.
4) Reading external sensor data uses predefined packet.

The whole data collecting includes wake-up process, response waiting process, data transfer process, idle time-out process and sleep packet broadcasting process. Users can refer to the timing sequence of hybrid sleep mode in Figure 7. For the pure synchronous sleep mode, there is no wake-up process so it can be regarded as a special case of hybrid sleep mode. We need to calculate the time and current in each process and then get the total power consumption in fulfilling the whole data collecting in wireless sensor network.

5.1 Asynchronous wake-up process.

The MNET III uses short packet to wake up in asynchronous sleep mode. The time **Tw** is related to the number of neighboring nodes. More nodes means needing less wake-up time. In default setting the time needing for wake-up **Tw** is about 0.1~1 time of **Ts**. We adopt the maximum value 1 **Ts** so the wake-up time is **Tw==Ts**. In the process we assuming the modules work in transmit status in 1/2 **Tw** and in receive status in another 1/2 **Tw**. The current of module will be (**Ir** + **It**)/2.

5.2 Response waiting process.

For external sensor, it needs ADC sampling on analogue parameter and the values of analogue current or voltage needs to become steady only after the sensor is powered on for some time. The correct sensor data can be obtained after a delay time **Td** when the node module triggers the sensor. If **Tw** is less than **Td**, the node module will be in receive status in the period of **Td-Tw** after wake-up process and the current will be **Ir**.

5.3 Data transfer process

MNET III protocol in network modules adopts 5 times of hand-shaking for data transfer. If there is no data bumping in the process of hand-shaking, the time for all the hand-shaking is **Tos**= [764bits/**B** + (2***L***8)/**B** +2ms]

Among which **B** refers to the default RF data rate and **L** refers to the length of data frame.in byte. The total time **Tt** needing for collecting the data of all nodes in the network is:

Tt = = n * **Tos** / (N*∫)

'∫' is the data transfer efficiency which is determined by the distribution of node modules. The value range is 25% ~75%. The typical value is 50%.

The nodes with highest power consumption will be those closest to the concentrator modules. Because these nodes are mostly used as relay nodes so the data output are very high and the RF circuit works for the longest time. Considering the worst situation, these node modules will work in transmit mode in the half time of Tt and in receive mode in another half time so the average current in this process is **(Ir + It)**/2.

5.4 Idle time-out process

If the concentrator manipulates the synchronous sleep mode, the idle time-out will be used as the ending of data transfer. In this process no data flow exists in the network and all node modules are in receive mode so the average current is **Ir**. If users use ATCS command to control the synchronous sleep mode, the current in this process can be reduced to the least, even zero.

5.5 Sleep packet broadcasting process

The time in this process is very short in synchronous sleep mode and it only needs to send a few bytes through 1~5 times of hand-shaking. More neighboring nodes mean less hand-shaking times. Comparing to the whole process of data collecting, the power consumption in this process can be omitted.

Process Type	Time	Current	Explanation
Asynchronous wake-up	Tw	(Ir + It) /2	Optional
Response waiting	Td-Tw	Ir	Optional
Data transfer	Tt	(Ir + It) /2	Required
Idle time-out	To	Ir	Optional

Table 1: Current in Different Processes

In summary asynchronous wake-up process, response waiting process and idle time-out process can be omitted in some applications so they are optional but the data transfer process is necessary. Users can shorten optional processes in application in order to reduce the power consumption. An example on power consumption calculation is showed as below:

1) The number of nodes **N**=1;
2) The number of concentrator **n**=1;
3) The length of data frame **L**=64;
4) RF data rate **B**=250 kbps;
5) The delay time of external sensor **Td**=200ms;
6) Asynchronous Sleep-Wake Rate: 100;

7) Idle time-out **To**=2000ms;
8) Receive current **Ir**=20mA; Transmit current **It**=33mA, Sleep current **Is**=0.5uA.

According to Wake-Sleep Rate and RF data rate, the configuration tool gives the default parameters: Back off Tick=128us and Auto Wake Slot= 18 ticks so the period of wake and sleep in asynchronous sleep mode **Ts** = 128us * 18 ticks *(100+1) =233ms.

Because **Ts** is larger than **Td**, the response waiting process can be omitted. The effective time for one data transfer can be calculated as **Tos** = [764bits/250kbps + (2*64*8)/250kbps +2ms] =9.152ms. The total time for the data transfer in the network is Tt = n*Tos / (N*∫) = 100*9.125ms/(1*50%) = 1.83s (∫ uses the typical value 50%). In conclusion the time in the first four processes are 0.23s, 0s, 1.83s and 2s correspondingly so the total time in the whole process is 4.06s and the average current is 23mA according to receive and transmit current.

Note: 1. the idle time-out is 2s in the example, which occupies nearly 1/2 of the total working time. Users can use other methods to judge the ending of data transfer to shorten the working time and reduce the power consumption.
2. The number of concentrator is 1. In applications users can add more concentrators to improve the bandwidth of network and reduce the time of data transfer.

6. APPLICATION

In this section we will take HC2 series of humidity and temperature sensors from ROTRONIC as example and introduce how to configure the parameters of DRF1110N modules to establish a wireless sensor network.

HC2 series of sensors have extensive applications in HVAC, food storage, building automation, semiconductor industry, paper manufacturing, meteorological, etc. The relative humidity of HC2 probes range from 0% to 100% with resolution ±0.5% and the temperature ranges from -40 to 100℃ with resolution ±0.1℃. HC2 series of probes have one analogue output and one digital output. The digital output uses UART interface (Baud rate: 19.2kbps, no check ,no flow control, 8-bit data and 1 stop bit and it adopts RO-ASII protocol. The working voltage is 3.2~5V DC. The initializing time is 1.5s after power-on and current is 5~8mA. The HC2 probe itself does not have sleep function. In order to obtain low power consumption, the HC2 is powered up by ACT pin of DRF1110N module.

6.1 Protocol configuration

RO-ASCII is the default communication protocol used in Airchip 3000 products by ROTRONIC, which is applied but not limited to HC2, HF3, HF4, HF6, HL20 and HP21 series of products. The command frame of RO-ASCII is showed as below:

'{'	ID	Address	Command	Data	Checksum	CR

Table 2: Frame Structure in RO-ASCII

- {: starting character of frame
- ID: equipment type, 1 ASCII character
- Address: RS485 address (00~64), 2 bytes, 99 is the broadcasting address
- Command: command type, 3 ASCII characters
- Data: variable ASCII characters
- Checksum: checksum, can be replaced by '}'
- CR ending character of frame, carriage return character

RDD is the Read command. The command for reading any sensor address is "{F99RDD}\r". For example:

DRF1110N send: {F99RDD}\r
HC2 response: {F04rdd 001;4.45;%RH;000;=;20.07;°C;000;=;Fp;-19.94;°C;000;+;001; B2.8; 0000000002;HyClp 2 ;006;J^M\r

Because each sensor has its unique serial number, we don't need to set RS485 address for it. For wireless sensor network based on DRF1110N modules, users can use RDD as data collecting command. The DRF1110N node modules don't need to analyze the serial number of sensor and only recognize RO-ASCII frame by the frame starting character '{' and ending character '}'. The related parameters on configuration tool are showed as below:

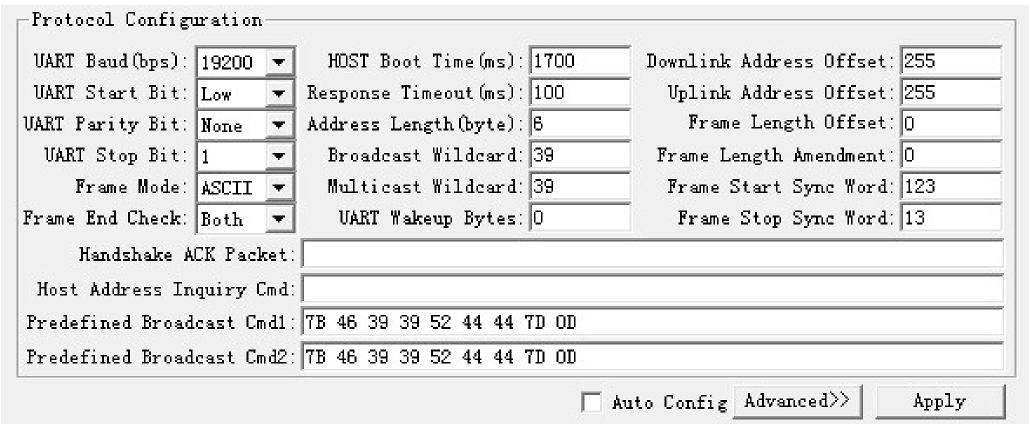

Figure 9: Protocol Configuration for RO-ASCII

Notes: 1. the HC2 probe can output correct temperature and humidity data after initializing time 1.5s. In order to guarantee the effectiveness of sensor data, the Host Boot Time is set to 1.7ms which is slightly higher.

2. The Predefined Broadcast Cmd1 and Cmd2 are all set to data read command '{F99RDD}\r' and the Frame Mode is ASCII.

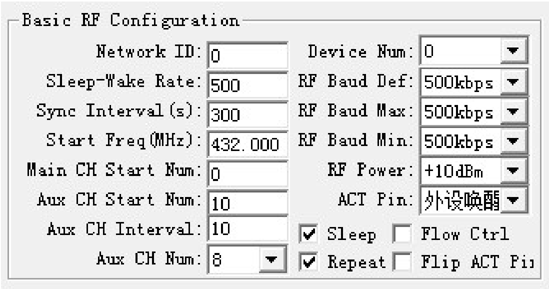

Figure 10: Basic RF Configuration for RO-ASCII

Notes: 1. Because the data frame length of HC2 probe is a little long, the RF Baudrate is 500kbps.

2. The power management of HC2 sensors is controlled by ACT pin of DRF1110N module so the ACT Pin is set to external device wake-up.
3. Since the initializing time of HC2 probe is 1.5s, longer asynchronous wake-up time is allowed so users can choose larger Sleep-Wake Rate to lower down power consumption of modules in idle period. It is set to 500 in this application.
4. The data sampling interval is set to 300s which will be the default value after power-on. The concentrator will collect the sensor data of all nodes per 5 minutes.
5. Sleep and Repeat function are enabled so the node modules can enter asynchronous sleep mode automatically and the concentrator module can collect data at preset interval.

6.2 Power Consumption Calculation

If there are 100pcs of HC2 sensors in one network, the values of related parameters are listed according to the conclusion in section 6.1

- The number of node modules **N**=100;
- The number of concentrator **n**=1;
- The length of data frame **L**=100 bytes;
- RF data rate **B**=500 kbps;
- The delay time of external sensor **Td**=1700ms;
- Asynchronous Sleep-Wake Rate: 500;
- Idle time-out **To**=2000ms;
- Receive current **Ir**=20mA; Transmit current **It**=110mA, **Is**=0.5uA.

The configuration tool gives the default parameters Backoff Tick=108us and Auto Wake Slot (tick)=15 so the period of wake and sleep in asynchronous Ts=108us*15*(500+1)=812ms. Considering the Tw (wake-up)=Ts=812ms which is less than the Td, the node module needs to wait for Td-Tw=888ms in receive mode. The effective time for one data transfer can be calculated as **Tos** = [764bits/500kbps + (2*100*8)/500kbps + 2ms] = 6.728ms. The total time for the data transfer in the network is **Tt** = n*Tos / (N*∫) = 100*6.728ms/(1*50%) = 1.35s (∫ uses the typical value 50%). In summary the time for asynchronous wake-up process, response waiting process, data transfer process and Idle time-out process are 0.812s, 0.888s, 1.35s and 2s correspondingly so the total time for data collection is 5.06s. If we don't consider the power consumption of sensor module, the average current in work time slice is 39.66mA according to the transmit current and receive current. If the module is powered up by 1000mAh battery and data collecting interval is 5 minutes, the module can work uninterrupted for about 63days. If the data collecting interval is 10 minutes, the module can work 126 days.

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